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INTEGRATED SYSTEMS OF MANUFACTURE (ROBOTICS) TECHNOLOGY WORKING GROUP REPORT

(IDA/OSD R&M STUDY)

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RB Robot Corporation
Working Group Chairman

November 1983

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SCIENCE AND TECHNOLOGY DIVISION

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This document records the activities and presents the findings of the Integrated Systems of Manufacture (Robotics) Technology Working Group, part of the IDA/OSD Reliability and Maintainability Study conducted during the period from July 1982 through August 1983.

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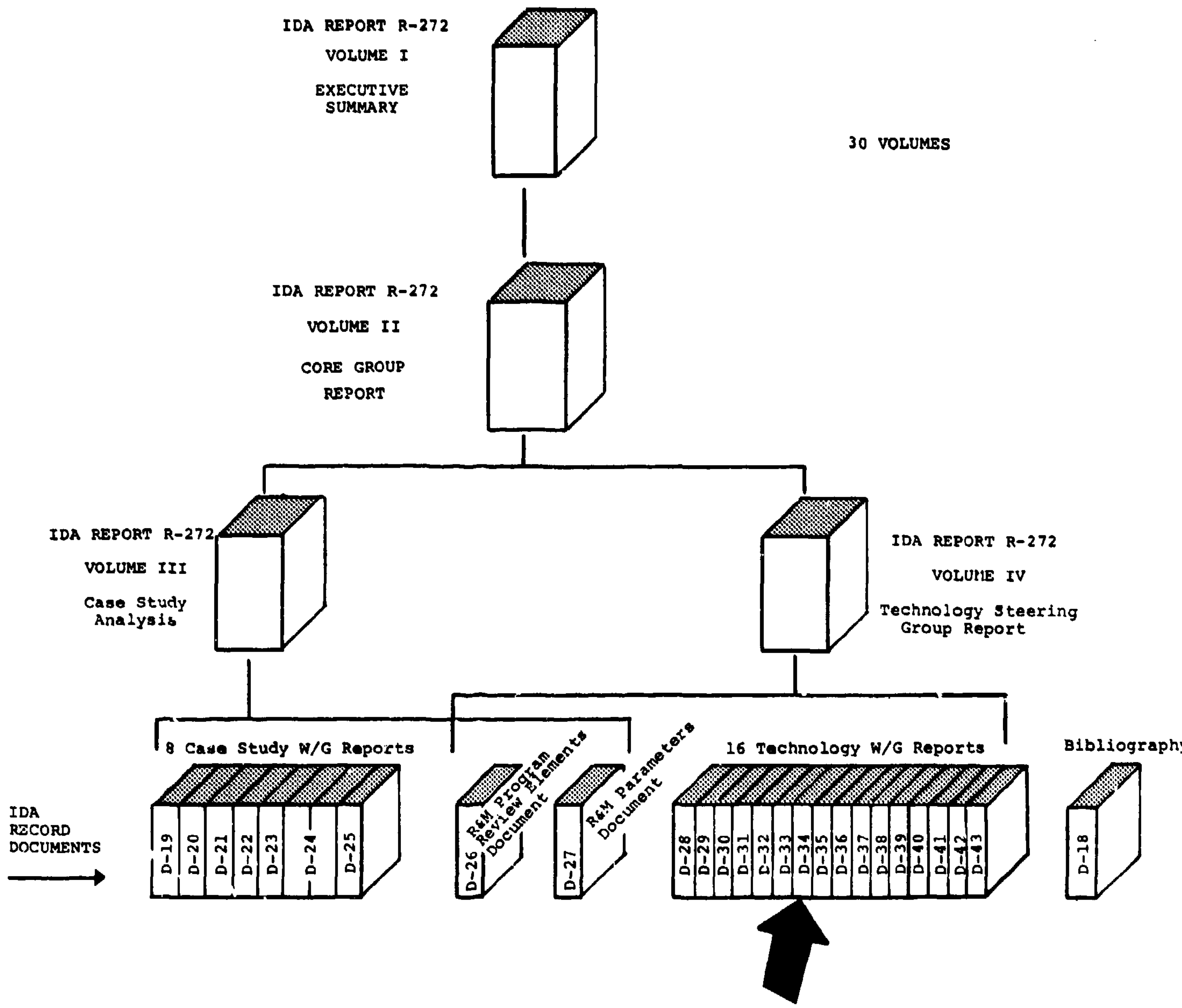
RELIABILITY AND MAINTAINABILITY STUDY

— REPORT STRUCTURE —



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PREFACE

As a result of the 1981 Defense Science Board Summer Study on Operational Readiness, Task Order T-2-126 was generated to look at potential steps toward improving the Material Readiness Posture of DoD (Short Title: R&M Study). This task order was structured to address the improvement of R&M and readiness through innovative program structuring and applications of new and advancing technology. Volume I summarizes the total study activity. Volume II integrates analysis relative to Volume III, program structuring aspects, and Volume IV, new and advancing technology aspects.

The objective of this study as defined by the task order is:

> "Identify and provide support for high payoff actions which the DoD can take to improve the military system design, development and support process so as to provide quantum improvement in R&M and readiness through innovative uses of advancing technology and program structure."

The scope of this study as defined by the task order is:

> To (1) identify high-payoff areas where the DoD could improve current system design, development program structure and system support policies, with the objective of enhancing peacetime availability of major weapons systems and the potential to make a rapid transition to high wartime activity rates, to sustain such rates and to do so with the most economical use of scarce resources possible, (2) assess the impact of advancing technology on the recommended approaches and guidelines, and (3) evaluate the potential and recommend strategies that might result in quantum increases in R&M or readiness through innovative uses of advancing technology.

The approach taken for the study was focused on producing meaningful implementable recommendations substantiated by quantitative data with implementation plans and vehicles to be provided where practical. To accomplish this, emphasis was placed upon the elucidation and integration of the expert knowledge and experience of engineers, developers, managers, testers and users involved with the complete acquisition cycle of weapons systems programs as well as upon supporting analysis. A search was conducted through major industrial companies, a director was selected and the following general plan was adopted.

General Study Plan

- Vol. III • Select, analyze and review existing successful program
- Vol. IV • Analyze and review related new and advanced technology
- Vol. II (• Analyze and integrate review results
  (• Develop, coordinate and refine new concepts
- Vol. I • Present new concepts to DoD with implementation plan and recommendations for application.

The approach to implementing the plan was based on an executive council core group for organization, analysis, integration and continuity; making extensive use of working groups, heavy military and industry involvement and participation, and coordination and refinement through joint industry/service analysis and review. Overall study organization is shown in Fig. P-1.

The basic technology study approach was to build a foundation for analysis and to analyze areas of technology to surface: technology available today which might be applied more broadly; technology which requires demonstration to finalize and reduce risk; and technology which requires action today to provide reliable and maintainable systems in the future. Program structuring implications were also considered. Tools used to accomplish

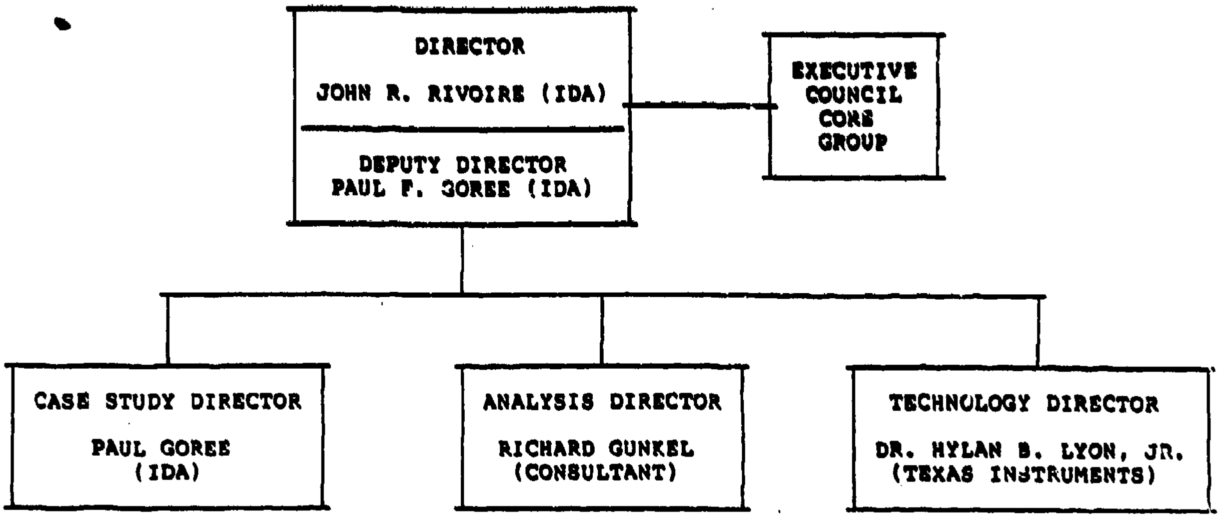

FIGURE P-1. Study Organization

this were existing documents, reports and study efforts such as the Militarily Critical Technologies List. To accomplish the technology studies, sixteen working groups were formed and the organization shown in Fig. P-2 was established.

This document records the activities and findings of the Technology Working Group for the specific technology as indicated in Fig. P-2. The views expressed within this document are those of the working group only. Publication of this document does not indicate endorsement by IDA, its staff, or its sponsoring agencies.

Without the detailed efforts, energies, patience and candidness of those intimately involved in the technologies studied, this technology study effort would not have been possible within the time and resources available.

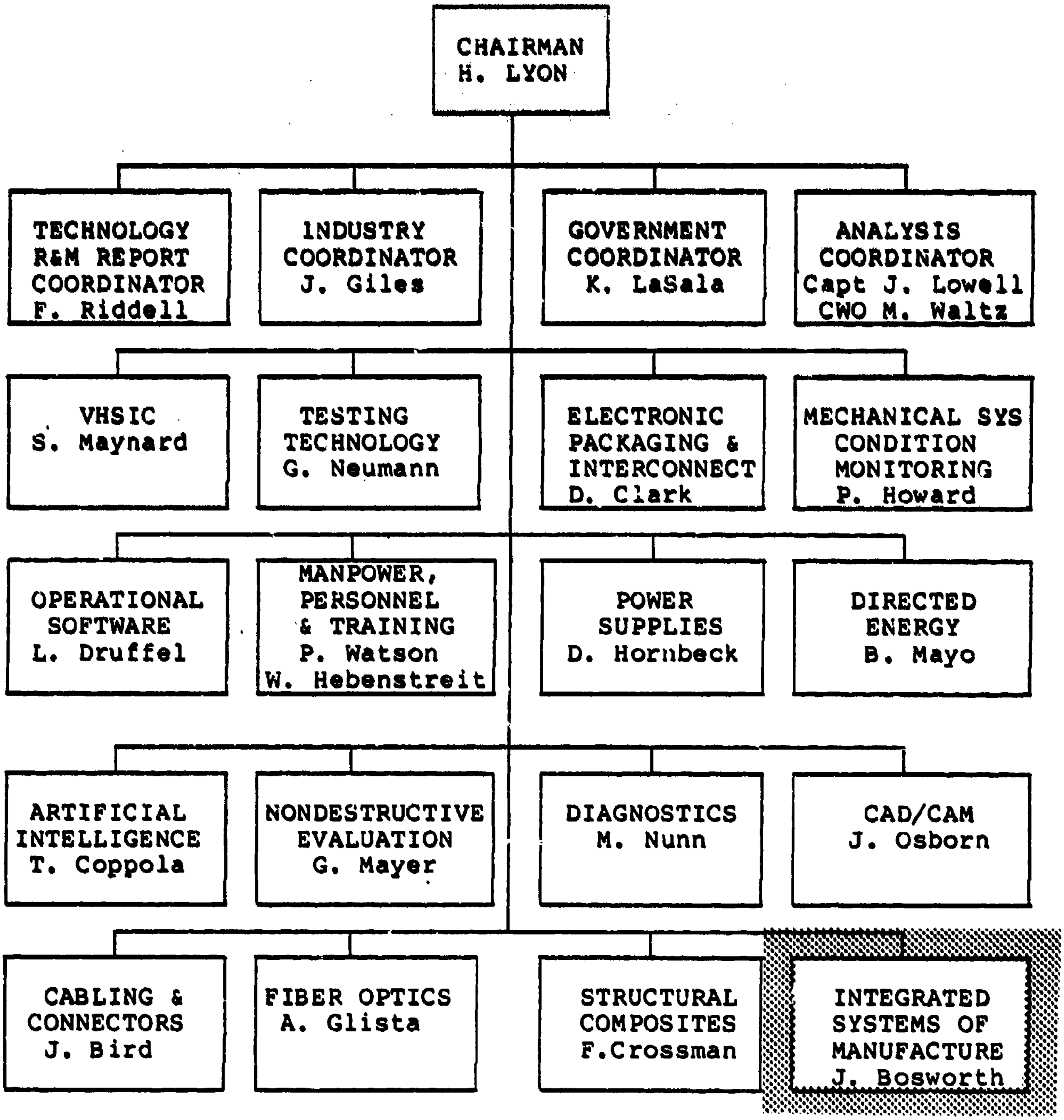

FIGURE P-2. Technology Study Organization

INTEGRATED SYSTEMS OF MANUFACTURE
(ROBOTICS)

FINAL REPORT

NOVEMBER 1983

DEFINITION OF ROBOTICS

The American National Standards Institute (ANSI) definition of industrial automation is probably the best existing definition of robotics (except for this report's Introduction and Summary):

> "Industrial automation encompasses the application of multiple technologies in a coordinated programmable systems approach to the complete manufacturing process. These technologies include, but are not limited to, information systems, equipment, and telecommunications."

Add to this definition the concept of automation applied to maintenance as well, and change the term automation to systems of manufacture (and maintenance) or robotics and we have the working definition we need for this report.

STATEMENT OF WORK

INTEGRATED SYSTEMS OF MANUFACTURE
(ROBOTICS)

Goal: To identify ways in which robotics can be applied to bring major improvements to reliability and maintainability (R&M) and readiness.

Scope: Dealing with the multidisciplinary nature of robotics technology, this effort focuses on existing applications of robotics in industry as well as emerging applications that have immediate and important implications for DoD R&M and readiness. Primary emphasis is given to robotics implementations involving:

- Sensor technology
- Computers
- Electronics
- Mechanical engineering
- Other physical sciences
- Energy
- Communications

Issues:

1. Robotics in service and maintenance
2. Robotics . small lot production
3. Universal robotics language (software)
4. Robotic diagnostic systems

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INTRODUCTION AND SUMMARY

The potential impact to the Department of Defense (DoD) of robotics or the technologies of automation is best understood when considered not in its nuts and bolts, but as an overall way of doing business.

We have known and practiced for some time the theories of cybernetics and information feedback loops. Robotics is the implementation of those principles in close-knit physical systems, be they in an automated facility that manufactures an aircraft or in an automated depot that inspects and repairs the aircraft or in the aircraft itself. In each of these instances -- manufacture, maintenance, and the system (aircraft) itself -- information about the environment is (1) gathered with sensors, (2) processed with computers through algorithms or against data bases, then (3) translated into action, whether it is mechanical, chemical, radio magnetic actions or whatever.

These closely fused systems of technology, known variously as control systems, robots, flexible manufacturing systems, work cells or intelligent task automation, are all diverse implementations of the same family of disciplines that we call robotics and that are essentially the basis of all modern systems that incorporate information feedback in their operation. The technologies of robotics include but are not limited to:

Electronics
Computers
Communications
Artificial Intelligence
Mechanical Engineering
Physics

Other Physical Sciences
Energy
Systems Analysis

The nature of this particular study has been to determine how robotics can contribute to quantum improvements in the reliability and maintainability of DoD equipment.

The answers to this question are no less far reaching than the foregoing definition of robotics itself. Once reliability and maintainability of an end system has been thoroughly considered and treated in feasibility and design, robotics can then be employed in the timely, economic, and effective implementation (manufacture) of the design.

Perhaps more important, it has been suggested that, of all of DoD's equipment planned to be in use in the year 2000, 60 percent of that equipment is already in existence today. Therefore, the operational readiness of our inventory in the year 2000 will still be greatly dependent on the effectiveness of our maintenance systems. Robotics in maintenance is essentially a wholly untapped and strategic consideration for operational readiness in the coming years.

To develop the potential that robotics has for reliability and maintainability, DoD must take the following three major steps:

1. Further evolve the existing modernization programs within DoD and the individual services into DoD-wide procurement guidelines and procedures designed to apply the full weight of DoD's procurement budget toward the development of robotic technologies as a major underpinning of equipment reliability and maintainability.

2. Train targeted managers and professionals throughout the military services in the evaluation and specification of robotic or automated systems.

3. Mature the technology of robotics (off-line) with a program of mission-oriented robotics projects focused on reliability and maintainability, and ranging from small lot manufacture to automated maintenance facilities.

This report explores the current state of robotics in both the commercial and defense sectors, and attempts to focus on the more dramatic implications of robotics on the operational readiness for DoD.

REPORT ON INTEGRATED SYSTEMS OF MANUFACTURE
(ROBOTICS)

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SECTION I.

EVOLUTIONARY INFUSION OF ROBOTIC TECHNOLOGY INTO DESIGN AND MANUFACTURING

A. THE GENERAL QUESTIONS AND SCOPE

A general sense among many within the Office of the Secretary of Defense (OSD) and the Department of Defense (DoD) is that our defense systems cost too much and take too long to develop, don't work when we get them, and are expensive to maintain. Of course, this is grossly over-simplified and maligns many a good and successful project, past and present.

Nevetherless, these descriptors fit too many procurements that can be cited.

Two major efforts are currently underway within OSD to provide direction in correcting these circumstances.

1. The Defense Science Board Task Force on Reducing Risk During Transition From Development to Production, chaired by Willis J. Willoughby, Jr. This effort has focused on engineering principles that must be incorporated into the project management of all procurements, from development through production, and holds the promise of significantly reducing the risk of over-schedule, over-budget and under-engineered projects.

2. The technology study entitled Sustaining Performance Through Technology, conducted by the Institute for Defense Analysis (IDA) and more particularly, the Technology Steering Group (TSG), chaired by Dr. Hyland Lyons of Texas Instruments. The TSG has focused on the technology causes and contributions to reliability and maintainability (R&M) and is resulting in a series of recommendations for demonstration projects and technology maturation programs that can significantly improve the reliability and maintainability of DoD equipment.

Integrated systems of manufacturing or, for short, robotics is a systems technology that can not only provide more timely and cost effective manufacturing of DoD equipment, but can contribute significantly to R&M as this review describes.

An important finding of this review is that robotics in maintenance has as much, if not more, to contribute to R&M as does robotics in manufacturing. The prospect in maintenance is that dramatic improvements in cost and performance can be achieved through the following three steps.

1. Computer-aided maintenance systems, as a prerequisite for integrating automation into maintenance routines, will reap schedule and cost economies in and of themselves.

2. Then, man-in-the-loop maintenance systems will incorporate the best of what machines (and computers) can do today with the critical skills of trained personnel as the glue that holds these systems together.

3. Finally, enough will be learned in this evolutionary process to forge fully automated systems, in time, that will incorporate the know-how and experience of our most skilled personnel, who in turn will be employed (in fewer numbers per task, but over more tasks) to continually monitor and improve the systems.

Small lot manufacture can and will certainly follow the same evolutionary path.

Requiring our major contractors to deliver fully developed and tested computer-aided maintenance systems, and then semi-automated and fully automated maintenance systems with their products, is certainly an idea whose time will come very shortly. Such systems will render much more practical the management of life-cycle costs and life-cycle reliability and maintainability of equipment, given that contractors can then be held much more accountable for the life-cycle performance of their systems.

This study can only hope to raise a number of the issues to be considered and certain of the directions to travel, in tapping the potential that robotics holds for reliability and maintainability. It is hoped that the varied materials that are included in this document will provide the reader with sufficient perspective to initiate some efforts and to pursue the issues further.

B. COMMERCIAL SECTOR

CASE HISTORIES
RELIABILITY/MAINTAINABILITY PAYOFF OF ROBOTICS IMPLEMENTATIONS

APPLICATION	CATEGORY	ROBOT FUNCTION	MAJOR BENEFITS OF USING ROBOT(S)
B-1 Golf ball manufacture	Reliability in manufacturing golf balls	Pick-and-place freshly-painted golf balls from spray line to drying rack	o Human operators were dropping thousands of golf balls a week o Human operators were leaving "pick marks" o A properly-aligned robot does not drop balls or leave "pick marks"
B-2 Cleaning cooling water intake pipes in a Japanese utility company power generation plant	Maintainability of sea water intake pipes	Maintenance (scrape deposits of algae and shellfish from inside wall of seawater intake pipe without suspending water intake)	o Cleaning could be accomplished without suspending water intake o 90% reduction in pipe cleaning cost and time (savings of millions of yen)
B-3 Automotive forgings and castings	Reliability in manufacturing automotive parts	Inspection via artificial vision for surface cracks using dye penetrant and ultraviolet illumination	o Allows inspection of 100% of parts o Eliminates errors by fatigued human inspectors.
B-4 Arc welding	Reliability of structures fabricated by welding	Fabrication via seam tracking and arc control	o Automatic control of weld parameters o Seam tracking o Eliminates errors by fatigued human operators
B-5 Assembly in manufacturing	Reliability of assembled systems, e.g., circuit boards	Assembly	Increased productivity through more reliable units per unit time than human assemblers can make

CASE B-1

DESIGNING CUSTOM ROBOTS FOR IN-PLANT USE

Robert A. Brown
Acushnet Company
New Bedford, Massachusetts

INTRODUCTION

In 1977, the Acushnet Company decided to make a major commitment to improved product quality and lower manufacturing costs by designing new automatic equipment for our Titleist golf ball plant.

We considered applying conventional machine design approaches using cams and air cylinders, as well as a robotic approach. For various reasons, we divided the automation tasks between conventional and robotic design groups.

Both approaches have been highly successful. The conventional approach has resulted in the complete automation of the ball cover and core assembly, automatic buffing of the flash caused by the cover molding operation, and automatic orientation and stamping of the name and number on the finished ball.

The robotic approach was applied to the tasks of automatically winding golf balls and then automatically removing freshly painted golf balls from a moving conveyor following spray paint operaitons.

I will discuss the paint spray robot application in this paper as an example of Designing Custom Robots for In-Plant Use.

The robotic approach is a method of generating positional Variety (V) using the minimum number of actuators. Variety is defined as the number of different things, considered as a whole, that can happen.

When X = number of distinct stopping positions of the robot on each axis,

and n = number of axes of the robot,

then $V = X^n$.

Assuming a resolution of .2% of the range of each axis and a three-axis robot, then X=250, n=3 and

$$V = 500^3 = 125,000,000 \text{ possible positions.}$$

A conventional machine capable of generating the same variety using 2 position actuators would require

$$2^n = 125,000,000$$

or $n = 27$ actuators.

Historically, painted balls were manually unloaded from the painted ball conveyor onto drying trays and loaded into trucks for holding in a drying room.

It took three operators to unload balls from each spray booth conveyor. We had seven booths operating three shifts for a total of six operators. Our goal was to automatically load unpainted balls onto trays, and then use a single operator to move loaded trays and trucks from several booths. The balls are first loaded onto the ball conveyor from a hopper which stores enough balls for several hours of painting.

The balls are then sprayed at over 100 balls per minute in a conventional spray booth.

The robot unloader picks and places four balls into specially designed trays having a staggered 2" spacing for maximum packing density. The total cycle time, including returning to the ball conveyor ready for the next pick, is less than two seconds.

The tray conveyor indexes and feeds trays in conjunction with the robot. It automatically "downstacks" empty trays at one end and "upstacks" the loaded trays at the other end.

The main control cabinet monitors and controls the whole paint spray system, including robot, tray conveyor, spray booth, and stack vent sensors. The programmable controller includes the five custom fabricated motor drive cards in the control cabinet.

The programmable controller "supervises" the system operation, but due to its relatively low operating speed, custom-built, high-speed controllers were required for each of the stepping motors.

A ball box representing four golf balls is placed in the gripper. The rotation, vertical position, and extension for the 12 trajectories are then checked against scribed lines on the calibration table.

We attempt to adjust all axes to within $\pm$.010", which is equivalent to $\pm$ one pulse of the stepping motor. However, this is not always possible due to flex within the robot. This is an inherent problem with all robot systems. If you try to establish its position when the robot is wound up either through deceleration or vibration, the gripper will be in a slightly different position when it is at rest. This problem can be dealt with in our system by tailoring the trajectories to minimize acceleration and jerk during critical robot homing periods in the program.

These robots, like all machines, occasionally experience malfunctions. These incidents can be classified in terms of "crashes" or "crunches." Pushing the reset button gets you out of a crash as it does with most computer crashes. In a crunch, something gets bent or broken. These can be avoided by laying out the work space whenever possible so as to tolerate the "loss" of an axis. The motors, gearing, and shafting should be sized so that the motors simply stall if something jams. Step motors are excellent for this purpose.

It sometimes helps to make the system flexible so that it will also bend over obstacles. Sometimes these overload precautions hamper the operation of the system. A motor sized to stall may stll due to a momentary peak force due to vibration or backlash. Also, a limber system will have larger, lower frequency oscillations at the end effector. However, some unnecessary shutdowns and more time for homing may be less costly than one big crunch.

Whenever there is a system failure, the question arises: "Is it a mechanical, electrical, or computer problem?" This clearly defines the three team members required to get a robot system going and keep it going. It has been our experience that a very high level of performance is required in all three disciplines in order to obtain a robot system upon which the whole organization can depend.

RESULTS

One of the greatest advantages that came out of the paint spray automation effort was a large reduction in the number of dropped wet balls. In spite of the skill and dilgence of the manual operators, thousands of freshly painted balls were dropped each week. These have to be stripped and repainted at great expense. When properly aligned, the robot system does not drop balls.

Pick marks on the balls are practically eliminated due to the precise pursuit and capture method used by the robot. Production was increased due to ability of the robot system to operate through lunch and coffee breaks. The payback was less than one year based upon direct charges made for machine fabrication and installation.

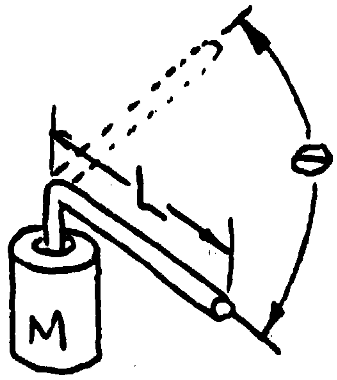
The automatic painting system operates approximately 23 hours a day, five to six days a week. The first system has been operating for two years. Two other systems are in operation and four more are being fabricated at this time. Once a day, while the booth is shut down to refill the spray gun and clean the ball support spindles, parts of the robot are lightly oiled by the machine operator. Then once a week, the robot is wiped down and reoiled. Aside from this, our operating uptime has exceeded 97%, and preventative maintenance requirements have been minimal. We intend to overhaul each robot every year or so to replace drive belts, spline and high helix drive shafts, and flex cabling.

CONCLUSION

The most important lesson learned from this effort is the relation of robot size to performance. We learned from the very beginning that we could not obtain rapid cycle times if we reached too far or made the robot too big.

The following formula shows the relation of the power required to rotate a solid round arm of length L through an angle θ in time t having a density D with a modulus of elasticity of E, and a flex deflection of d_{max}.

$$P = \frac{4 \pi L^7 D^2 \theta^2}{3 E d_{max} t^3}$$



CASE B-2

CLEANING SEAWATER INTAKE PIPES

Seawater is an effective cooling medium for Japan's 130 power generation plants. One problem, however, is that algae and shellfish like barnacles and oysters grow on the walls of the plants' cooling water intake pipes. The marine life hinders water flow. And, when the organisms come off the walls, they can enter condensers, causing blockage and corrosion.

To help reduce the severity of the problem, Japanese power companies regularly hire divers to clean the pipes, or the pipes are cleaned after the water is drained from them. "Cleaning typically takes about a month and costs tens of millions of yen," according to Mitsubishi Heavy Industries Ltd., Tokyo.

A 90% reduction in both pipe cleaning time and cost is now said to be possible thanks to the development by Mitsubishi and Tokyo Electric Power Co. of a remote controlled underwater robot capable of scraping marine life off open and closed pipes without suspending water intake.

The robot consists of a glass fiber reinforced plastic body eqipped with impellers, brushes, wheels, and a television camera; a diesel engine/hydraulic pump power system; hydraulic hose takeup equipment; and controls for remote operation.

The robot pushes its wheels against the pipe wall, cleaning it with water jets from the two impellers and the rotating brushes.

A single, above-water operator monitors a TV screen and manipulates levers to move the robot and control impeller and brush rotation.

CASE B-3

INSPECTION OF FORGINGS AND CASTINGS

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ABSTRACT

The last 12 months have seen a rapid growth in the range, variety, and number of artificial vision applications in factory use. This rapid expansion is the result of the rapid increase in versatility and capability of relatively low-cost, artificial vision systems. These have been used increasingly as eyes for the robots in assembly and arc welding, as well as on-kline vision inspection during production processes and off-line inspection of finished products. This paper discusses the new Autovision 4 as an example of such modern artificial vision system and its application across a broad spectrum of industrial applications selected from the automotive, electronics, and computer industries, and discusses future areas of growth.

The factory-hardened unit is packaged in a sealed cabinet to protect it from harsh industrial environments including fumes, corrosive atmospheres, and metallic dust as well as electronic noise.

Control inputs and outputs are through opto isolators. As compared to the second generation, Autovision II, the processing speed has been increased by a factor of two to five times.

The Autovision 4 reprocessing and vision processing capability are also available in an integrated configuration with a robot controller, the AI324(tm) controller for robot guidance applications and visual inspection or servoing. Whereas the second generation Autovision II is limited to eight cameras, the Autovision 4 can support sixteen cameras. This can result in very low cost per station for applciaitons requiring visual inspection at moderate speed. The cost per station when using multiple cameras can be as low as $3,000 to $5,500 depending on the camera used and therefore, are down to a small fraction of the annual cost of a single human inspector.

Artificial Vision applications are highly diversified and so ease of adapting artificial vision systems to many different applications is crucial. In the case of the Autovision 4 three levels of user programming are possible: 1. Application programming using the RAIL language at the Autovision 4, or remotely through off-line programming in this mode. A manufacturing engineer, who need not be a software engineer, can write programs for stand-alone operation or to be used in a menu-driven dialogue manner for use by the machine operator. 2. PASCAl language programming to provide analytical capabilities not currently available in the RAIL user language. 3. Specialized data pre-processing algorithms or techniques for novel applications, data formats, etc., which can be written in assembly language.

ARTIFICIAL VISION INSPECTION APPLICATIONS

The range of visual inspection applications has greatly increased as a result of recent advances in technology. One current use of the technology is for inspecting simple parts at high speed of up to 2,200 holes per minute. This inspection of a 90 hole automotive stamping is in production use at a major automobile manufacturer. The inspecting system shuts down the stamping line system if any of the holes deemed critical are either missing or incorrect.

Representatives of more sophisticated applications can be demonstrated with a typical process control, in which an instrument cluster under test can be inspected at high spped to determine the correctness of both analog outputs (dials) and digital outputs, such as segments of a liquid crystal display and indicator lamps.

A similar application is an experimental application for a watch manufacturer who plans to use the vision system to command a special purpose fixture that on command depresses the proper watch buttons to set the correct time on newly manufactured digital watches. In this use, the artificial vision system observes the display, compares the results with its own real time clock, and signals the system when to stop cycling. The system will also verify the quality of the display during cycling.

Another system using artificial vision inspects gaps both between car doors and car bodies and car hoods and car bodies on an automotive assembly line. The artificial vision system takes a large number of three dimensional readings, typically 80 in 35 seconds, and then does a statistical analysis on the readings and communicates the information to earlier stations on the assembly line. If the process is drifting out of tolerance, it

can be corrected before it reslts in faulty final assembly, in which the car-door-to-car-body gap is either too tight or too loose.

An example of an entirely different class of application is the use for rapid non-destructive testing for flaws in castings or forgings. This involves combining an artificial vision system with a classical magnetic dye penetrant and ultraviolet illumination technique. The forged automotive part is magnetized, immersed in the dye, and then placed under ultraviolet illumination and inspected by the Autovision system to find dye that has seeped into cracks. The high speed system can simultaneously inspect both sides of this forging at the rate of 60 per minute.

In the case of inspection -- where the average rate of defective parts is already below one in a hundred, and even more when it is below 1 in 1000 -- Artificial Vision becomes far more effective than the human inspector who must deal with the monotony problem of 999 cries of "wolf" followed by a single defect, a condition in which human performance is particularly poor.

On hundred percent inspection of simple parts to replace the implicit inspection by the human operator no longer present in robotic or other automated assembly tasks is another growing area. A Cybervision(R) III system supports a sophisticated application of a robotic assembly system for the batch insertion of keytops in keyboards. In this system, keytops are inserted -- using a series of vibratory bowl feeders -- in long tubes after being automatically inspected by the vision system which also 100% verifies the quality of the keytop labels. The second or Robotic Assembly station, can then proceed to insert the keys "knowing" that 100% good parts have been provided and that poorly labeled or wrongly labeled keys have been discarded.

An interesting and colorful application combining two classes of requirements is an experimental application to properly affix labels on champagne bottles. In this application, the customer wishes to ensure the alignment of the various labels on the champagne bottle and at the same time wishes to ensure that the bottle is filled to an exact fill level.

Another production line application, this time involving color discrimination using gray tones, comes from the pharmaceutical industry. A manufacturer of birth control pills wishes to ensure that each compartment of a transparent plastic package contains a pill and, further, that the pill in each compartment is of the correct type as determined by its color.

With the use of multiple cameras on a single artificial vision system, the cost per station often makes possible the combining of several inspection operations on an economical basis.

ROBOT POSITION CONTROL

The Autovision 4 system is now being used in an increasingly broad range of visual servoing applications with the camera located either in the hand of the robot or at a fixed location. These applications occur particularly in connection with robot arc welding. In those cases where full-visual servoing is not necessary--that is, where the problem is only lack of repeatability of the exact location of the part to be arc welded--the function of the Artificial Vision system is to determine, in three dimensions, the location and orientation of the part and to provide that information to the robot controller. Thus, a coordinate conversion is applied to ensure that the preprogrammed welding path is correctly executed on the shifted part. This technique, known as Vision Offset, permits welding of a less than ideally fixtured part or even, if desired, unfixtured parts.

A conventional assembly application, demonstrated at Robots VI in 1982, shows the assembly of a small pulse transformer where the part-to-part variations are too great to permit successful assembly without individual correction for each part. In these kinds of applications, the vision system is also frequently used to verify the correctness of the part as well as its position and that of its mating surfaces.

In small-part electronic applications, the same combination of visual inspection and determination of exact location - in this case pin location - is sometimes required to ensure successful insertion. The verification of relay cans to ensure that the correct part is being inserted, that it is not rotated 180° and, if necessary, to allow an offset to ensure that the pins, as observed by the camera, can be correctly inserted into the printed circuit board.

CASE B-4

U.S. INDUSTRY NEEDS IN ROBOTIC WELDING TECHNOLOGY

Robert D. Sigman

PROJECTED ROBOTIC WELDING GROWTH

The United States welding robot installations currently number about 2300 units, 2000 spotwelding robots and 300 arc welding robots. The growth projections for the year 1990 are for 22,000 units, 12,000 spot welding robots and 10,000 arc welding robots. The current recession has severly impacted robot growth, down 15% from the 1981 levels, largely due to the reduced automotive industry purchases.

The robot growth rate in the U.S. between 1985 and 1990 for arc welding robots will be 57%. As the automotive industry saturates spot welding applications, sales will slow significantly in favor of arc welding robots. The unit growth of spot welding robots should remain stable at a 20 to 23% rate through the 1980s. The market demand in arc welding robots will stimulate welding sensor technology development.

The projected increase in the use of robots for welding will demand that U.S. welding technology advance to support this growth. the welding processes, materials and consumables must improve with the advancing robot capabilities to get maximum productivity gains.

ARC WELDING

Arc welding robots represent a new dimension in welding. They provide programmable automatic welding and are fast becoming a strong influence in a field that to date is largely manual and, in some cases, semi-automatic or mechanized. Robotic systems offer increased productivity, product quality, safety and economic return, and have proven track records in many applications. They will have a significant impact on welding operations in the coming years.

A robotic arc welding system consists of a multitude of integrated components, specified, selected and designed to accommodate particular applications, while retaining flexibility. This paper addresses the hardware and software ingredients of a robotic system, and considerations for either purchasing a turn-key system or pursuing internal design and development, and the definition of responsibilities between the user and robot supplier.

Robots are classified as flexible automation and are effectively used in dynamic situations where parts are varied. They are also used where production levels are lower than the volume required to justify hard automation.

With a robot, an arc welding work cell may be multipurposed and able to service many forms; part design changes may simply be made be reprogramming the robot, as opposed to extensive equipment modifications.

The integration of a robotic arc welding system into a manufacturing operation may assume many forms. In the simplest arrangement, the operator works in parallel with the robot. The load and unload activity occurs while the robot is welding at another station, resulting in production improvement. Additional efficiencies can be realized by slaving automated auxiliary devices such as positioners and material handlers to the robot, with all elements performing a coordinated sequence of events. In the ultimate scheme, the robot is a member of a flexible manufacturing system where all production activities, welding units, positioners, material handling, etc. are controlled by a host computer that maintains material flow, load balance, inspection and system diagnostics.

System Planning

The most crucial effort in robotic system implementation is the initial planning. Many associated factors must be analyzed before the system concept can be defined. This important activity can help to assure equipment and process compatibility and ultimate success. The key areas to be analyzed are parts selection and processing; robot selection, welding equipment selection; auxiliary equipment selection; facility requirements; operations activities and human factors.

Parts Selection and Processing

The components to be welded in the robotic work cell should be thoroughly evaluated in the following manner. The parts must be compatible with the robotic system equipment. The high robot duty cycle requires an evaluation of heat inputs and associated part distortions. Components should be selected such that

manual secondary operations are minimised and only used to supplement the robotic welding activity in areas with limited torch access.

Components should be examined with regard to the part repeatabilities and the quality of the weld joints. Components should be examined with fixture concepts in mind such that fixture components do not limit robot torch accessibility. It may be desirable to perform most welds in the flat position and the parts should be evaulated accordingly. Minimise robot arm articulation that may cause a change in wire cast and result in the welding arc wandering out of the weld joint. A simplified method of group technology may be applied where large numbers of different components are to be handled so fixtures can become multi-purposed. A simplified form of value engineering may be applied to identify part design changes that could offer improvements in robotic welding, as well as reduce material and processing costs.

Robot Selection

Industrial welding robots are available with numerous work zone configurations, axes, features, options, repeatabilities, velocities, interface capabilities, and intelligence levels. The robot shall be selected to satisfy the intended application as well as provide additional capability for production modification and changes. There are several primary robot characteristics that play an important role in the actual welding and in the system integration.

Robot Work Zone. It is obvious that the robot work zone and number of axes must be matched to the part sizes and shapes. A fact that is not readily apparent is that the articulations of the arm and wrist required to maintain torch position often substantially reduce available robot travels within the work

zone below the manufacturer's specifications. Difficulties of this nature can be avoided through CAD/CAM simulation or by verifying the specified articulations by mocking up the robot and test specimens before installation.

The robot work zone should be evaluated in terms of supporting multiple operating stations. In this manner, the work cell efficiency increases significantly since part unloading and loading may be parallel with robot welding. The techniques that can be used are:

The work station is rotated or translated into the robot work zone; and/or

The selected robot is capable of physically reaching multiple fixed stations.

Robot Velocities. The robot must be capable of moving at variable velocities as required by the welding process and to proceed along the programmed weld path in a consistent manner. The robot should also have the ability to delay at the start of the weld until the puddle is established and to delay at the completion of the weld after motion stops.

Robot Repeatabilities. Robot repeatability must be evaluated against weld size, expected quality level, part fit-up, and location tolerances. It is important to note that larger weld sizes are more forgiving and that small welds require better robot and part repeatability.

Robot Search Tracking of the Weld Joint. To reduce the part preparation cost of the product, it may be desirable to select a robot with the ability to search for the weld joint before welding and to track the weld joint with a real time arc sensor. These robots can search either side of the seam and correct the program for the start of the weld location.

During the welding cycle, real-time arc sensing allows the welding arc to follow the weld joint movement. This corrected path can be stored for recall and may be offset a predetermined amount from the path of the original tracked pass if a multiple pass weld is required.

Weld Parameter Control. The robot control should have the capability to allow weld parameters to be set for each weld and if necessary to be varied from joint-to-joint as they have been pre-programmed. There are two ways in which this is normally accomplished:

A multi-schedule power supply unit activated by an output signal from the robot can be used. The robot output signal is matched with the power supply, and recalled at the specific programmed point. This scheme permits fine tuning of the weld parameters using potentiometers during the weld cycle; however, the voltages and wire feeds must be manually set and are not part of the stored robot program.

Power supply voltages and wire filter metal speeds can be controlled by robot programmed entries. In this case, a special interface unit normally is required so that the robot can properly communicate with the power supply to produce the proper parameters.

Robot Interface Capabilities. The robot should be equipped with sufficient input and output capabilities to handle the system requirements. Examples of important robot I/O for a welding system follows:

Robot Inputs

- o External part program selection
- o Part present at work station "signals"
- o Arc established "signals" before motion starts
- o Safety sensors indicated unauthorized personnel in work zone to inhibit motion
- o Fixture clamped or unclamped "signals"
- o Indexing device or material handler, "in position signals"
- o Weld schedule selection
- o Weld start and stop
- o Preweld and postweld purge
- o Index commands to positioners or material handlers
- o Commands to fixture clamping or unclamping devices

Robot Memory and Available Programs. Robot systems that must handle complicated welds or a large variation of parts should be examined for appropriate memory size and number of available programs. Robot manufacturers offer several techniques of artificially expanding a robot memory capability: disc storage or other mass memory techniques; cassette data tapes; and download capabilities from a host computer such as DNC or other equivalent devices.

The most efficient method is dictated by the frequency of change required for a particular application and the size of the resident robot memory.

Robot Program Selection. Systems that randomly handle a large variation of parts should be equipped with the ability to externally select the proper work routine. Several techniques which may be used are operator panel push button, card reader or bar-code reader input, download capabilities from host computers and other sensory inputs that define the part.

__Weave Capabilities__. Welding robots may be required to perfom and weave patterns particularly in "out of position" large and multipass welds, and in arc tracking conditions. Weave patterns can be variable, programmable, and have the following characteristics: number of cycles per inch or pattern definition; amplitude of ascillation; dwell period at right of oscillation; dwell period at left of oscillation.

__Special Features__. Robot manufacturers have recognized special needs for arc welding automation and the following items are currently available:

- o Adaptive control for tracking the seam with the arc or in the presence of the arc.
- o Techniques to locate the start of the joint.
- o Memorizing of the tracked first pass for subsequent multiple passes.
- o Digitizing or examining the seam before welding and providing the necessary corrections during the weld cycle.
- o Protection of electronic equipment from RF noise associated with high frequency GTAW starts.
- o Off-line programming capabilities.

The use of these items is dependent upon particular application requirements and should be discussed in detail with the robot manufacturer.

Welding Equipment

Arc welding equipment used in robotic systems is generally the conventional type of machine that has been purchased with several added and unique features. Some important aspects of robotic welding equipment follow:

- Multi-schedule or robot control interface capabilities.
- High duty cycle characteristics that correspond to the high robot level of arc-time for torch and power supply.
- Breakaway torch mounts which preclude damage in a collision or electrode or filler metal sticking situation.
- Larger wire filler metal spools that may be floor mounted as opposed to the smaller arm mounted spools that require more frequent change.
- Automatic burn-back control.
- Simulation capabilities that permit the system to be checked out without initiating an arc.
- Capability to use multiple gas mixtures as the welding process changes, part to part.
- Wire filler metal drive system that contains a wire straightening mechanism.
- Frequency modulated "pulse GMA" power source to reduce weld spatter and afford out of position welding - lead photograph.

Auxiliary Equipment

The auxiliary equipment used in a robotic work cell may be a number of various-components designed for the application and the desired level of automation. Normally, the auxiliary devices are controlled by the robot so that all functions are coordinated. Examples of auxiliary devices are welding positioners, rotary tables, and head stock devices; nozzle cleaning stations and anti-spatter applicators; material handlers such as conveyors and pallet movers; remote operator pendant control consoles; and automatic fixturing.

Facility Requirements

Plant site selection for a robotic installation requires the following considerations:

- Floor loading, power, space and utility requirements, as defined by the robot manufacturer, must be analyzed.
- The activities or other equipment in the adjacent shop areas must be considered and their impact recognized, such as GTA welding and potential effects upon the robot electronics.
- The robot should be placed in an area conducive to proper shop product flow.
- Consideration must be given to the material handling of raw parts into the robotic cell and finished components out of the cell, in addition to the necessary queuing areas.

- Future robotic or automated activities and planned shop rearrangement should be considered in the site selection.

Operation Activity

At the time when the robotic system is installed in a plant, there are numerous activities that should be considered:

- Extensive operator training with backup personnel.
- Extensive maintenance training in both the mechanical and electrical aspects of the system.
- Safety training.
- Complete spare parts inventory for the robot, welding equipment and auxiliary devices.
- Complete inventory of welding perishables.
- Modified scheduling techniques that effectively use robot work cell and minimize fixture changeovers.
- Complete system documentation to minimize troubleshooting techniques.
- Welding processes should be evaluated so that the welding parameters can be defined and altered in the robot system to improve arc time.

Human Factors

The degree of success in any robotic installation is strongly dependent upon the amount of attention and planning directed toward the human factors. Much investigation has been done in this area, and summaries of several important aspects follow.

Systems Safety. The robotic work cell should be designed for maximum safety of the operators and other personnel. This includes both direct and indirect methods such as proper operator training and a thorough knowledge of the equipment; ongoing safety training programs.

Indoctrination. Operator acceptance is expected to be significantly greater if shop personnel are exposed to the details of the planned robotic system before installation.

Operator Involvement. Shop operations personnel should be consulted for technical details during all phases of a robotic installation. This approach will produce valuable technical assistance and can promote an attitude of involvement that may be crucial for success.

User/Supplier Responsibilities

Previous sections of this paper were directed toward developing a basic description of a robotic arc welding cell. At this point, the potential user may have a brief understanding of the necessary ingredients which are characteristic of such a system. However, the potential user may not be fully aware of the levels of effort required, nor the division of responsibility between user and robot vendor. It is important to recognize that the purchase of a so called "turn-key system" does not imply that the user's effort is reduced to a minimum level. The

implementation of a robotics cell requires a thorough understanding of plant operations, which normally resides solely with the user.

C. Defense Sector

APPLICATION CATEGORY		ROBOT FUNCTION	MAJOR BENEFITS OF USING ROBOT(S)
C-1 Navy robotic deriveter/aircraft airframes	Maintainability of aircraft exposed to salt water corrosion	Inspection (with an ultrasonic sensor) and maintenance (remove rivets)	Increased productivity, as compared to a human operator
C-2 Manufacture of a small number of parts or components	Maintainability, e.g., on board ships, space stations	Manufacture a part when needed	Eliminates need for a large inventory of spare parts which are infrequently needed

CASE C-1

NAVY ROBOTIC DERIVETER

In the near future, the use of robots in DoD systems manufacturing will increase in parallel with industry. Maintenance and repair departments at intermediate- and depot-level activities will begin to use robots as the technology matures to the point where robots can deal with the complications and variations associated with such work. An example is the Navy Robotic Deriveter, which entered a two-year development program beginning in fiscal year 1981. Deriveting is necessary because salt water causes corrosion damage to airframes, which must then be dismantled for repair. That time-consuming, tedious, repetitive task will be done by a robot using an ultrasonic sensor and commonsense artificial intelligence to "learn" the rivet pattern, rapidly inspect the airframe structure around each rivet, and remove the rivets. The system will be able to handle several sizes of rivets in a variety of patterns on many different aircraft types.

STATE OF AUTOMATION IN THE DEFENSE SECTOR

- DEFENSE IS SPONSORING R&D
  - INTELLIGENT TASK AUTOMATION PROJECT - AIR FORCE
  - AUTOMATED MANUFACTURING RESEARCH FACILITY (AMRF) OF THE NATIONAL BUREAU OF STANDARDS - NAVY
  - DoD WILL SPEND AT LEAST $72 MILLION IN 1983 ON BATTLEFIELD ROBOT DEVELOPMENT
  - DEFENSE IS SPURRING COMMERCIAL DEVELOPMENT
  - INDUSTRIAL MODERNIZATION INCENTIVE PROGRAM (IMIP) - DoD
  - INTEGRATED COMPUTER AIDED MANUFACTURING (ICAM) - AIR FORCE
  - AVCO LYCOMING - FMS SYSTEMS MANUFACTURING PARTS FOR AIRCRAFT ENGINES AND GAS TURBINE ENGINE FOR M-1 TANK - ARMY TECHNOLOGY MODERNIZATION PROGRAM

D. COMPARISON OF DoD AND COMMERCIAL USE OF ROBOTICS

It is totally beyond the scope of this study to provide a defintive and quantitive review of robotics in these sectors. However, the following comments as well as a number of the appendicies may prove helpful in providing more insight into the commercial and defense applications of robotics.

The charts on the following two pages characterize certain of the uses of robotics in the commercial and defense sectors.

STATE OF AUTOMATION IN THE COMMERCIAL SECTOR

- THERE ARE CURRENTLY ONLY 25 TO 30 FLEXIBLE MANUFACTURING SYSTEMS (FMS), COSTING BETWEEN $10 AND 20 MILLION, IN COMMERCIAL USE IN THE U.S.

- LESS THAN 5% OF ALL MACHINE TOOLS IN THE U.S. ARE NUMERICALLY CONTROLLED (NC) OR COMPUTER NUMERICALLY CONTROLLED (CNC) EVEN AFTER 30 YEARS SINCE INTRODUCTION OF THIS TECHNOLOGY.

- THE JAPANESE ARE MAKING A BID TO SEIZE THE LEAD IN DEVELOPMENT AS WELL AS APPLICATION OF THE ROBOTICS TECHNOLOGIES THROUGH A CONSORTIUM OF ALL THE MAJOR JAPANESE MANUFACTURERS AND LED BY THE MINISTRY OF INDUSTRIAL TRADE AND TECHNOLOGY (MITI)

SECTION II.

SELECTED ROBOTICS ACTIVITIES WITHIN DoD

A. INTELLIGENT-TASK AUTOMATION PROJECT

The Materials Laboratory at Wright-Patterson Air Force Base and the Defense Advanced Research Projects Agency (DARPA) have jointly awarded a $3.35 million contract for real-time touch and vision sensors, micromanipulators, and controls for robots and manufacturing automation systems. The project leader, Honeywell, is responsible for the sensors, controls, system integration, and computer hardware and software development.

The other three team members and their general responsibilities are: Stanford University--basic robotics research and artificial intelligence; SRI International--applied robotics research; and Unimation--robot development and manufacture. The Electronics and Materials Lab of the Air Force Office of Scientific Research is also involved in the project, although not in its funding.

Honeywell and SRI are particularly concerned with the integration of eye-hand coordination and are developing 3-D vision systems that are fast enough for their needs. They are currently planning to use three cameras: two 2 1/2-D low-resolution cameras--one positioned on the wrist to look through the hand and another to be positioned at a different angle for verification; and a 3-D high-resolution camera to oversee the entire operation. (2 1/2-D involves planar imaging plus "sparse ranging"--the depth notation of selected points.)

The Honeywell group plans to use a multi-bus distributed processor, but a supplier has not been chosen. The robot now being adapted is a Unimation PUMA 560, operating under the newly developed VAL-II language. It should be noted

that the final configuration of the vision and handling system is not yet established.

The $3.35 million is only for Phase One of the contract, which ends in December 1984. At that time, the sensing subsystems are to be demonstrated, and the contract is to be reviewed. Phase Two should culminate in the automated assembly of a microswitch from a tray of 12 randomly oriented parts. (Selection from a bin, involving more complex spatial adjustments, will come later.) Future military applications may involve "surrogate soldiers," for repairing equipment or rescuing human soldiers under fire.

The Materials Lab and DARPA have also authorized $3.25 million (since raised to $4.8 million) for development of "two coordinated robotic arms for assembly and inspection." The prime contractor is Martin-Marietta, and the team also consists of Virginia Polytechnic Institute of Michigan. Phase One of this contract will end in 1985.

B. REPRESENTATIVE FOCUS ON ROBOTIC APPLICATIONS FOR THE U.S. NAVY

- o Primary Areas Affected by Robotics (Vis. R&M and Readiness for the Navy):

- <u>Development:</u> Not direct impact (indirectly, robotics technology must be reflected in system designs).

- <u>Production:</u> Improve reliability due to greater control over manufacturing processes afforded by robotics (major impact of robotics on industrial base readiness, as opposed to operational readiness, is beyond scope of study).

- <u>Operation:</u> Major impact on manpower as robotics is used for wide variety of tasks ranging from supply loading and refueling to mine field detonation--which translates directly into improved readiness and lower life cycle cost.

- <u>Maintenance:</u> Major impact of a wide range of maintenance activities, from routine cleaning to rebuild operations and emergency repairs.

BACKGROUND

The Navy is currently reviewing its options in planning for naval requirements in the 1990s. Strategic decisions regarding new shipbuilding and modernization of existing ships are of critical importance today. The total number of ships in the U.S. Navy declined from over 1,000 in the late 1960s to slightly under 550 at present. Naval ship production in recent years has been at a considerably lower volume than it was during the 1960s. By the 1990s, many ships built during the higher production period of the 1960s will reach 30 years of age and likely be retired. In order to maintain an adequate level of naval forces through the remainder of this century, programs for modernization of existing ships will be required in addition to increased levels of new ship authorization.

Ship modernization is a means of achieving qualitative superiority at sea even though the number of ships may be at minimum acceptable levels. Although a ship's hull may last for 30 years, a combat system may become technologically obsolete in 10 years. By retrofitting state-of-the-art weapons systems onto existing ships, overall navy quality can be upgraded at considerably lower cost than through the construction of new ships.

The effect of a modernization program is to improve the overall capability of a ship (engagement range and firepower). At the same time, life cycle costs are lowered through more efficient usage of each ship. At a time when total operating costs over the life of a ship can be as high as the initial procurement cost, the Navy is concerned about determining ways to reduce life cycle costs.

An important component of total ship cost is the cost of staffing. The size of a typical surface combatant is determined

by the amount of armament and the crew size required to operate the ship. As larger accommodations are required, the construction cost of the ship increases. Therefore, any opportunity for reduction in crew size will have an impact on ship procurement cost as well as operating costs over the long term.

A reduction in staffing is desirable for other reasons. The Navy, like other U.S. military services, is experiencing serious combat readiness problems resulting from an inadequate number of experienced enlisted personnel. In addition to the problems affecting all military services, such as the perceived low level of military compensation, the Navy must deal with the morale problems resulting from long tours of duty at sea.

Many Naval personnel, faced with several months of separation from their families, are reluctant to reenlist, and as a result, the naval reenlistment rate has been lower than that of the combined services. Because of the relatively low retention rate of experienced Naval personnel, Naval forces are considered to be at only marginal combat readiness. Overall staffing is at 90% of the desired strength and staffing for supervisory noncommissioned offiers is only at 83% of authorized strength. In developing strategies for the 1990s, the Navy is thus attempting to address three basic issues:

- o Need for programs to reduce life cycle costs of ships (both initial and operating costs).

- o Need for improvements in ship capabilities.

- o Means of ensuring adequate staffing levels, either through higher recruitment/retention rates or through reductions in staffing level requirements.

In industry, similar issues are being addressed as manufacturing firms attempt to improve productivity. One highly promising new manufacturing technology being successfully employed by many companies is robotics, which is the use of industrial robots in manufacturing environments for assembly operations, welding, machining, painting, transporting, and other applications. Robots are currently being studied by representatives of many other types of environments for potential uses, including health institutions, nuclear plants, mining operations, agriculture, construction, space, undersea operations, and military services.

The Navy recognizes the potential benefits of robotics and is interested in determining the feasibility of using robotics in shipboard applications. To assess this feasibility, two tasks will need to be accomplished. First, an inventory of all shipboard labor performed on a representative ship must be conducted to determine specific activities that could be performed by robots. Second, a cost-benefit analysis must be developed to identify all costs associated with the transition to robotics (both quantitative and qualitative) and also the associated benefits to be realized. From this assessment, the Navy can then determine whether or not to make changes either in the design of the ships or in modernization programs.

The DD 963 has been suggested as the representative warship to be studied. This is the Spruance class destroyer, of which 31 ships are being built. It was designed primarily as an anti-submarine warfare (ASW) ship, using the SQS-53 sonar and ASROC sensor-weapon combination. The DD 963 would be employed as a surface combatant belonging to a major battle group. Although surface combatants now serve primarily an escort role for carriers, recent advances in technology (cruise missiles, ship-based helicopters, new antisubmarine sensors, and new

anti-air warfare systems) have considerably improved their capabilities and may place the surface combatant in an important position once again.

The DD 963, with a displacement of nearly 8,000 tons and accommodations for a crew of nearly 300, is a good example of a surface combatant that may be upgraded in importance. Although initially criticized for deficiencies in combat capability, it is being augmented with additional armament to greatly improve its capabilities.

POTENTIAL ROBOTICS APPLICATIONS

There are three fundamental tasks that can be performed by robots at the present time:

- Displacement--the movement of work pieces or other items, such as loading or unloading, conveying, and palletizing.
- Processing/Fabricating--the processing of an item in addition to moving it, such as assembly, welding, painting, or cutting.
- Inspection/Control--the inspection of an item for control purposes (dimensional or quality control).

These capabilities appear to have potential shipboard applications. The most likely areas of robotics applications, as shown in Exhibit A, would probably be found in the areas of maintenance, cleaning, and routine repairs. Here the displacement and processing capabilities of robots could have an impact on staffing requirements. There may also be applications in combat situations, such as loading and unloading ammunition or transporting ammunition.

In general, although a shipboard environment is considerably different from a manufacturing environment, the conditions necessary for using robots appear to be present on ships. Robots may have advantages where the work is dangerous, when the work is repetitive, when robots can perform better quality work than humans, or where robots can perform the work at lower cost. In determining potential applications, it will be necessary to consider the division of labor between humans and robots and the interactions between them. That is, which tasks should be performed entirely by robots, entirely by humans, or by both?

Because the field of robotics is new, it will be essential that this study consider likely new developments that may have shipboard applications in the future. New areas of research now underway include the following:

POTENTIAL SHIPBOARD APPLICATIONS OF ROBOTICS

EXHIBIT A

Shipboard Task	Robot Capability: Displacement	Robot Capability: Processing	Robot Capability: Inspection
Guidance/Navigation			
Maintenance (Painting, Waste)	x	x	x
Cleaning	x	x	x
Routine Repairs (Welding, Etc.)	x	x	
Emergency Repairs (Hull, Engine)	x	x	x
Supplies (Loading, Storage, Usage)	x		
Food Preparation	x	x	
Inspection (E.G., Hull)			x
Communications			
Ammunition Transport & Loading	x	x	
Fire Control		x	x
Search and Rescue	x	x	x

x = Potential Application

- Robot sensing capability--the ability of robots to sense (through contact or vision) the environment for monitoring, inspection, and positioning. Sensing capabilities are relatively undeveloped at present.

- Software/hardware design--improved computer linkages for programming robots.

- Locomotion--the ability of a robot to move among a predetermined path.

COST-BENEFIT ANALYSIS

The critical second phase of this investigation would involve a comprehensive analysis of all costs associated with a transition to shipboard robotics and a comparison with expected benefits. Both initial and operating costs and benefits will need to be considered in order to properly evaluate the total impact of shipboard robotics over the lifetime of a ship.

As a first step, categories of costs and benefits will need to be defined, and then both quantitative and qualitative impacts must be determined. Potential benefits of shipboard robotics include the following:

- Decrease in ship construction costs resulting from decreased need for accommodations.

- Lower operating costs because of reduced staffing levels.

- Higher retention rate because of lower staffing requirements.

- Improved morale of Naval personnel.

- Higher quality of available personnel.
- Increased combat readiness.
- Reduction in casualties in combat.
- Reduction in probability of human error.
- Lower repair costs.
- Improved capability during combat.

Several areas of potential cost increases also need to be considered:

- Initial development cost for robotics.
- Cost of ship design.
- Maintenance costs for robotics machinery.
- Cost of space required for robotics.
- Development risk.
- Potential negative impact on crew morale (e.g., increased boredom).
- Likelihood of errors in combat situations.

The model that compares these costs and benefits must consider short- and long-term implications, and it must relate these impacts to the objectives and strategies of the Navy in order to properly assess the opportunities for shipboard robotics.

C. DoD's INDUSTRIAL MODERNIZATION IMPROVEMENT PROGRAM

IMIP is a Department of Defense (DoD) program to encourage industry to invest in modernization of the U.S. Industrial Base.

The policy is described in Department of Defense Instruction (DODI) 5000.XX, "DoD Industrial Modernization Incentives Program" (DRAFT dated 7 July 82), now undergoing test.

IMIP includes the earlier Air Force Technology Modernization (TECH MOD) program.

IMIP (and TECH MOD) programs require use of analytic techniques developed under the USAF ICAM program. We will discuss these techniques later.

The General Dynamics (Fort Worth) F16 production modernization program was the prototype for the IMIP/TECH MOD program.

GD and USAF will share in the anticipated $500 million cost savings (on a run of 1388 aircraft).

USAF agreed to provide $25 million to GD to help finance the factory modernization program.

GD agreed to invest $100 million to implement the results of development program for factory modernization.

GD employed the top-down, structured analysis of the factory that is the keystone of the TECH MOD/IMIP. This technique, "Structured Analysis and Design Technique (SADT) /$IDEF_0$ (ICAM Definition Method, Version Zero)" was also used for the preparation of all project work plans.

SECTION III

ROBOT TECHNOLOGY

A. MACHINE VISION

Up to 50,000 machine vision systems will be in U.S. manufacturing plants within 10 years, and they will be priced below $10,000 by 1992, according to a recent Tech Tran Corp. study. At least one-third of them will be used in conjunction with robots. Improved machine vision systems were the highlights of the Chicago Robots 7 Conference and Exposition. Integrated camera and computer systems combined with robotic arms were featured by many companies. Even the state of Michigan's Environmental Research Institute has formed a commercial vision system company, Synthetic Vision Systems in Ann Arbor to promote the Cytocomputer III system, which uses high-resolution imaging to recognize object features at high speed.

Auto Industry

Doorposts of the Cadillac Cimarron and the Chevrolet Cavalier autos are welded by a four-robot arc welder using three-dimensional optical scanning. The Robot Optical Welding System (ROWS) uses a 3-D camera mounted on the wrist of each robot, making two passes over each area to be welded. The first pass is the vision pass to determine the correct welding path. The second pass is the actual welding pass in which the camera, linked by computer to the arc welder, guides the weld. This two-pass system is similar to Unimation's Univision II. The ROWS system was developed jointly by G.M., Cincinnati Milacron and Robotic Vision Systems, Melville, New York. In future developments, G.M. will be aiming for a single pass system to weld cars on the move in the assembly line rather than the off-line, two-pass system.

Ford, not to be outdone, has matched a vision system to an impulse laser welding system in their Batavia, Ohio,

transmission plant. A matrix-type camera examines the transmission shafts and locates the true center of the pins to be welded. Then, a controller processor instructs the impulse laser (Raytheon 501 type) in positioning the weld. One advantage of the laser weld is that the initial beam can be more intense than the rest of the pulse, causing greater melting at first, allowing both deep and shallow penetrations in hard-to-reach places.

Two Arms System

Twin robotic arms are wiring and soldering electric fans for Toshiba in Japan. One arm is equipped with a CCD (charge coupled device) camera to monitor object positions while the other arm performs the soldering. The system has 10 microcomputers linked together to process data and provide visual information in real-time manufacturing.

Irregular Joints

General Electric's WELDVISION SYSTEM steers a TIG (tungsten inert gas) welding robot along irregularly-shaped joints and seams making adjustments as it travels. Using lenses to look ahead of the welding electrode, the system anticipates variations. Welding speeds are expected to double according to G.E., who expects to start system deliveries in December 1983.

Honeywell

A two-year program to improve real-time intelligent vision, range, force and touch sensing of robots costing over $3 million has been contracted by the Department of Defense. Honeywell's Technology Strategy Center in Minneapolis will manage the program working with Stanford University, SRI

International and Unimation. To achieve 3-D vision, three cameras are used.

Scratches

Dent, bumps and scratches in shiny metal can be detected by a vision inspection system designed by Rensselaer Polytech, Troy, New York. A diffused light source projects a grid on the shiny metal surface. A TV camera connected to a computer measures the uniformity of the grid, interpreting converging lines as a dent and diverging lines as a bump. The camera also scans for scratches that reflect the light differently than the smooth surface does.

Other innovations in quality control inspection systems come from Automatix, Billerica, Massachusetts, and Bendix Automation, Dayton, Ohio. Automatix uses a statistical quality control software program to detect when a part's specification begins to drift from standard, allowing preventative action before the part becomes a reject. Bendix has developed their QUADRAX inspection system, which inspects different parts in any order without a skilled operator. Three different colored lights tell the operator if the part is accepted, marginal, or rejected. Bendix claims speeds three times faster than coordinate measuring machines.

B. TACTILE SENSORS

Mechanical fingers with 256 tactile sensors in the fingertip have been developed in France, at M.I.T.'s Artificial Intelligence Lab, and in Japan. Industrial applications will require recognizing and orienting objects grasped with an entire hand, calling for coordination among all the fingers.

The I-BOT 1 vision system includes an electrically driven parallel-jaw gripper equipped with both pressure and optical sensors. The interruption of a beam of light directed between the tips of the jaws alerts the control system to the presence of an object.

C. CHEMICAL SENSORS

Chemicals that respond to ultraviolet light not only guide robot mailcarts through office buildings but are also a key part of a new guidance system in which the chemical is coated over the part to be processed or the tool to be used. Instead of outside programming, this system from Natmar, Inc., Cincinnati, Ohio, uses an optical scanner to sense ultraviolet properties of the chemical to trigger a variety of manufacturing and material handling functions, including robotic arm movements.

D. VOICE RECOGNITION

Market researchers at International Resource Development, Norwalk, Connecticut, predict that commercial voice products will grow as follows:

(Amounts in millions)	1982	1984	1987
Voice Synthesis/Output	$15	$48	$237
Store-and-Forward Telephone Switching	6	32	274
Voice Recognition	5	25	270

The explosive growth of voice recognition between 1984 and 1987 is based on the anticipated expansion of user-friendly office information systems that will provide voice commands and feedback in distributed processing networks. The use of programmable chips and circuits adaptable to many types of computers including personal micros will make it practical. Recent developments in VLSI (very large integrated circuits) and speech-processing algorithms (software patterns) have also helped it along.

Texas Instruments

A major factor in the commercial field of voice applications has to be Texas Instruments (T.I.). Long dominant in the children toy and educational market, they have now added voice recognition to their new Professional/Personal Computer. They have also developed a Multibus version, which is a digital signal-processor board (SBSP 3001) with 32 seconds of vocabulary. T.I. claims that it can equate to 1000 words. The heart of the system is the TMS 320 chip, a 32-bit signal processor that can execute five million instructions per second.

T.I.'s commercial name for the computer add-on is NLI, Natural Language Interface; it has a structured and limited vocabulary. Competing in the very intense office market, T.I. is expected to sell at least 30,000 of these computers this year, many of which should include the voice recognition package.

The first inexpensive voice recognition products will be appearing on the mass market in August on the T.I. model 99 4/A home computer and in November on Atari's VCS 2600 and 5200 video games. Made by Milton Bradley, these devices will sell for under $90. They will recognize about 12 words, which the speaker must pronounce twice into the headset microphone for computer recognition. Atari and Milton Bradley are planning 18 different speech recognition games over the next three years.

Other Players

Interstate Electronics, Anaheim, California makes a voice recognition add-on for a DEC terminal, costing about $1300. They rely on pattern-matching.

Votan, Hayward, California, offers boards and systems for stand-alone speech recognition in quality control checking of factory production, in shipping and receiving departments, with 50 word vocabularies.

IBM research is developing speaker-independent vocabularies of over 5000 words requiring main-frame computers.

Verbex, Bedford, Massachusetts, is about to offer a high-end data entry terminal with a 300-word vocabulary for speaker-dependent applications.

Threshold Technology, Delran, New Jersey makes speech-recognition plug-in modules for the Hewlett-Packard Series 80 personal computers with 120 words of recognition.

Intel Corp. is producing chips containing speech algorithms so that their customers and OEMs can customize them.

The Japanese companies are concentrating on two separate markets. Hitachi, Sharp and Matsushita are more into consumer products with voice outputs. Toshiba has developed a CMOS chip that can record and synthesize 12 seconds of speech with no external RAM. NEC and Nippon Tel. and Tel. offer chips and full systems for speaker-dependent users with an unlimited Japanese vocabulary and speaker-independent models with a 128-word vocabulary.

Microvoice Systems, Laguna Hills, California, offers two minutes of speech in 16 separate phrases for $675.

Telephone companies such as Western Electric and Rolm are involved in the communication aspects of voice recognition/output.

European and British companies include Philips of Netherlands, Triangle Digital, Costronics, Logica Ltd. and Marconi Space. Logica's system is speaker-dependent with a 2000-word vocabulary and is called LOGOS.

Industrial Applications

Hitachi's speech recognition system to control machinery and palletizing by voice command was introduced last winter in Osaka, Japan and probably will not come to the U.S. for a while.

An industrial control system using programmed synthesized human speech is available from C.A. Briggs Co., Glenside, Pennsylvania. It alerts a machine operator to emergency conditions with specific corrective instructions in sentences of up to 12 words each.

E. ADDITIONAL RELEVANT TECHNOLOGIES

RELEVANT TECHNOLOGIES

Honeywell

- MICROPROCESSORS
- STORAGE – NON VOLATILE MEMORY, DISK
- DISPLAYS
  - TYPES
  - DISPLAYED MATERIAL
- AUTOMATED SPEECH TECHNOLOGY
- INTELLIGENT DECISION AIDING
- GAMING

MICROPROCESSORS

Honeywell

- INCREDIBLE PROLIFERATION
- ADVANTAGE OF ORDERS OF MAGNITUDE
  - REDUCTION IN SIZE AND POWER REQUIREMENTS FOR SAME CAPABILITY
- HIGH CAPABILITY SILICON CHIPS (E.G. VHSIC) WILL BE SUFFICIENT
- GaAs FOR SPECIAL PURPOSES IN MID 1990's

MICROPROCESSORS

Honeywell

- ITEM: 10 COMPUTERS WILL BE ABLE TO HANDLE ALL DATA PROCESSING NEEDS IN THE USA (IBM, 1947)

- 1979 PREDICTION: THERE WILL BE 700,000 COMPUTERS IN HOMES BY 1982 (ACTUAL: [illegible] COMPUTERS SOLD IN 1982 ALONE)

- CONCLUSIONS:
  - MORE APPLICATIONS THAN CONCEIVED OF EARLIER
  - INCREDIBLE PROLIFERATION
  - GREATER CAPABILITY AT EARLIER TIME
  - MICROPROCESSORS ARE BECOMING INDISPENSIBLE

MICROPROCESSORS

Honeywell

- MAJOR CHANGE IN USERS HAS LED TO A MAJOR CHANGE IN COMPUTERS
  - COMPUTERS ARE BECOMING TRANSPARENT THE USER MAY NEITHER KNOW NOR CARE THAT HE IS CONVERSING WITH A COMPUTER
  - COMPUTER USERS ARE OFTEN NOT EXPERTS - DON'T CARE ABOUT BITS, BYTES, OR PROGRAMMING - BUT DO CARE ABOUT WHAT THE COMPUTER CAN DO FOR THEM

- COMPUTERS ARE THEREFORE BECOMING "USER FRIENDLY"
  - LESS JARGON
  - EASIER, SELF-EVIDENT COMMANDS
  - FORGIVING OF ERRORS
  - EMBEDDED TRAINING, SELF-EVIDENT INTERFACE (TOUCH PANEL, RECONFIGURABLE KEYS)

MASS STORAGE

Honeywell

- OPTICAL DISK
- MEMORIES (E.G. BUBBLE MEMORY) WILL COMPETE WITH DISK IN CAPABILITY
- BOTH MAY REQUIRE REMOTE DATA SOURCE
  - SATELLITE
  - BATTLEFIELD DATA CENTER

HOW MEMORY CAPACITIES COMPARE

Honeywell

MEMORY DEVICE	STORAGE CAPACITY (MILLIONS OF CHARACTERS)
HUMAN BRAIN	125,000,000,000
NATIONAL ARCHIVES	12,000,000,000
IBM 3850 MAGNETIC CARTRIDGE	250,000,000
ENCYCLOPEDIA BRITANNICA	12,500,000
OPTICAL DISC MEMORY	12,500,000
MAGNETIC (HARD) DISC	313
FLOPPY DISC	2.5
BOOK	1.3

DATA: RCA CORP, ADVANCED TECHNOLOGY LABORATORIES

VIDEO AND OPTICAL STORAGE TECHNOLOGIES

Honeywell

- **ANALOG DEVICES: THE VIDEODISC**
  - COMPATIBLE WITH NTSC VIDEO STANDARDS
  - ORIENTED TOWARD RASTER SCAN DISPLAYS
  - PROVIDES FRAME-ORIENTED OUTPUTS INTENDED FOR HUMAN OPERATOR CONSUMPTION
- **DIGITAL DEVICES: THE OPTICAL STORAGE DISC**
  - OPTICAL EQUIVALENT OF THE MAGNETIC DISC
  - DISPLAY INDEPENDENT
  - PROVIDES COMPUTER SYSTEM MASS STORAGE
- **PHERIPHERAL DEVICES**
  - TECHNOLOGIES DEVELOPED AS BYPRODUCT OF OR ADJUNCT TO OPTICAL STORAGE DEVICES (e.g., VIDEO FRAME BUFFERS)

TRENDS IN VIDEODISC TECHNOLOGY

Honeywell

- MORE COMPANIES PRODUCING INDUSTRIAL VIDEODISC AS CONSUMER PLAYER MARKET STAGNATES
- INCREASING HARDWARE SOPHISTICATION OF DISC PLAYERS
  - SUBSTITUTION OF SEMICONDUCTOR LASER FOR GAS LASERS
  - DEVELOPMENT OF READ/WRITE DISKS (LIMITED AVAILABILITY BY 1990)
  - HARDWARE IMPLEMENTATION OF FREEZE-FRAME AUDIO
  - INCREASING AMOUNTS OF ROM
  - LONGER PLAYING TIME PER SIDE
- DEVELOPMENT OF VIDEODISC COURSEWARE AUTHORING ENVIRONMENTS TO MINIMIZE MANPOWER REQUIREMNTS
- PROLIFERATION OF INTERACTIVE VIDEO PRODUCTION HOUSES
- VIDEODISC WILL RAPIDLY LOSE GROUND IN LONG TERM TO DIGITAL OPTICAL RECORDERS
  - DIGITAL TECHNIQUES PROMISE MORE CAPABILITY/$

DISPLAYS

Honeywell

TYPES

- CRT IS PRESENT STANDARD; PLASMA BECOMING MORE COMMON
- FLAT PANEL TECHNOLOGY
  - LC
  - CRT
  - EL
- HIGH RESOLUTION LC USES LOW POWER AND IS VERY LIGHT*

DISPLAYED INFORMATION

- MOST INFORMATION PROVIDED NOW IS NOT SELF-EVIDENT
  - PARTS ID AND LOCATION
  - SCHEMATICS
  - VERBAL MATERIAL
  - TEST EQUIPMENT OUTPUT
- SMART, INTEGRATED DISPLAY
  - MEANINGFUL INDICATION OF FAULT AND WARNING
    - UNIVERSAL SYMBOLS
  - ARROWS TO NEXT STEP
  - SYSTEM DESCRIPTION
  - MINIMALIST APPROACH

ACCESS BY AUTOMATIC SPEECH

Honeywell

- SPEECH IS NATURAL MODE OF COMMUNICATION
- VOICE CONTROL OF FUNCTIONS
- INSTRUCTIONS SPOKEN TO TECHNICIAN
  - SUPPLEMENT DISPLAY
- PRESENT:
  - ISOLATED WORD RECOGNITION, SPEAKER DEPENDENT
  - RELATIVELY SMALL VOCABULARY SYNTHESIS
- WILL REQUIRE:
  - NATURAL LANGUAGE RECOGNITION AND GENERATION
  - INDEPENDENT OF SPEAKER, OR VOICE PRINT (MAGNIFIABLE) FOR SECURITY
  - DRAWBACKS ARE CONTEXT AND VOCABULARY SIZE
  - NATURAL LANGUAGE RECOGNITION MAY NOT BE ACHIEVED

USE OF AST IN SYSTEMS

Honeywell

RECOGNITION/INPUT

- HIGH VISUAL-MANUAL WORKLOAD
- HIGH TIME-SHARING TASKS
- DISCRETE MANUAL TASKS
- ANTHROPOMETRIC DIFFICULTY
- CRITICALITY
- INFORMATION RETRIEVAL
- VERBAL NATURE
- USER ACCEPTANCE

SYNTHESIS/OUTPUT

- FEEDBACK MODE WITH RECOGNITION
- CONVEYING EXACT INFORMATION
- WARNING INDICATORS
- COMPUTER INTERACTION FROM REMOTE SITE
- REPLACE VISUAL DISPLAYS

DATA BASES

Honeywell

- ON BOARD STORAGE OF COMPONENT MAINTENANCE HISTORY
- ENVIRONMENTAL, TEMPORAL, SEQUENTIAL CONDITIONS LEADING UP TO FAULT
- QUERY COMPONENT WITH STANDARD INTERFACE
  - BIT RESULTS TO COMPONENT SIMULATION IN PERFORMANCE AIDS
- PROBABILITY ESTIMATION OF FAULT BEYOND BIT
- SELF–MODIFIABLE BASED ON COMPONENT HISTORY
- TROUBLESHOOTING GUIDED BY THESE DATA BASES

GENERATION AND MODIFICATION OF DATA

Honeywell

- NATURAL LANGUAGE PROGRAMMING
- VOICE PROGRAMMING
- CAD FOR TEST PROGRAM GENERATION
- "WHOLE SYSTEM" MODELLING
- MODIFICATION AT PERSONAL LEVEL BY VOICE
  - ELECTRONIC NOTE TAKING

ARTIFICIAL INTELLIGENCE

Honeywell

- MACHINE EMULATING INTELLIGENCE THE TURING PRINCIPLE - ARTIFICIAL INTELLIGENCE HAS BEEN ACHIEVED IF A HUMAN CANNOT DIFFERENITATE BETWEEN AN INTERACTION WITH THE MACHINE AND WITH A HUMAN
- MOST WORK DONE IN ACADEMIA, TO LEARN ABOUT HUMAN INTELLIGENCE
- APPLICATIONS ARE BECOMING PARAMOUNT - MAY NOT COMPLETELY MEET TURING CRITERION
- PRESENTLY BEING TOUTED AS AN ANSWER TO MANY PROBLEMS
- A RISE AND FALL HISTORY
  - THE "IN TEN YEARS" PHENOMENON

INTELLIGENT DECISION AIDING

Honeywell

- PART OF ARTIFICIAL INTELLIGENCE
- KNOWLEDGEABLE CAPTURE AND CODIFICATION FROM EXPERT
- AIDS NOVICE TO BECOME EXPERT
- TROUBLESHOOT AND REPAIR BEYOND BIT
- MINIMALIST APPROACH FOR EXPERT
- SHORT-CIRCUIT TIME TO BECOME EXPERT
- DRAWBACKS – COST AND TIME

CHARACTERISTICS OF INTERACTION WITH EXPERT SYSTEMS FOR INTELLIGENT DECISION AIDING

Honeywell

- USER
  - CONVERSES WITH SYSTEM BY TAPING IN ENGLISH
  - SUPPLIES RELEVANT INFORMATION (e.g., SYMPTOM OR DATA)
  - RESPONDS TO SYSTEM QUERIES (e.g., MORE DATA, CONFIDENCE ESTIMATES
- SYSTEM ESTIMATES LIKELIHOOD OF VARIOUS ALTERNATIVE EXPLANATIONS OR STATES SOLUTIONS
- SYSTEM CAN RESPOND TO QUERY REGARDING CURRENT ACTIVITY OR LINE OF REASONING (e.g., WHY IT HAS POSED A CERTAIN QUESTION)
- SYSTEMATIZES KNOWLEDGE OF MANY SPECIALISTS OF DIVERSE EXPERIENCE; IMPROVES AND REFINES KNOWLEDGE FROM TUTORIAL INTERACTION WITH DOMAIN SPECIALISTS

VIDEO GAMES

Honeywell

- INCREDIBLE, INTRINSIC MOTIVATIONAL PROPERTIES

  THREE VARIABLES -- (MALONE, 1980)

  1) CHALLENGE
     - VARIABLE DIFFICULTY LEVEL
     - MULTIPLE LEVEL GOALS
     - HIDDEN INFORMATION
     - RANDOMNESS
     - TIME AND PERFORMANCE STANDARDS
  2) CURIOSITY
     - SENSORY - LIGHT, SOUND
     - COGNITIVE - PROBLEM SOLVING, STRATEGY
  3) FANTASY

- CAN WE MOTIVATE TECHNICIANS AND OPERATORS USING THESE PRINCIPLES?

BATTLE DAMAGE REPAIR

Honeywell

- SURGE ENVIRONMENT
- "MEATBALL" MAINTENANCE – PRIORITIES CRITICAL
- WORK AROUNDS AND FIELD EXPEDIENTS
- NUCLEAR, BIOLOGICAL, CHEMICAL ENVIRONMENTS
- PERFORMED BY ASSESSOR AND TECHNICIAN
- TRAINING MAY NOT OCCUR

POSSIBLE MAINTENANCE AIDS

Honeywell

- SKIN CODES AND SCANNER
- SURROGATE TROUBLESHOOTING, MODEL BASED REPAIR
- EXPERT SYSTEM
- REPAIR ROBOTS WITH INTEGRATED COCKPIT SENSORS AND CONTROLS
- PORTABLE DEPOT

SECTION IV.

METHODS FOR THE EVALUATION AND SPECIFICATION OF ROBOTIC SYSTEMS

A. **USAF ICAM PROGRAM (Integrated Computer-Aided Manufacturing)**

The USAF ICAM program is a large ($100 million) program that has the objective of developing new methods/approaches to factory modernization, demonstrating the effectiveness of the new methods/designs, and transferring the new technology to the U.S. industrial community.

USAF provides "seed money" for contractors to accomplish the development of the new technology. Contracts are for "coalitions" of contractors, including a prime contractor, say Northrop, with other participating contractors, say, Lockheed and Boeing, plus a university and private consulting firms. The intent is to obtain maximum generality of results and maximum acceptance by the industry.

- **Factory Analysis**

  The foundation of the ICAM approach is the factory analysis, which leads to a factory architecture (how the factory operates now). The factory analysis includes a function model, an information model, and a dynamic model.

  Creation of the factory architecture:

  - Leads to a better understanding of how the factory actually works at present.

  - Helps to identify problem areas (disproportionately expensive operations, operations that contribute to poor quality, Human Factors-related problems)

- oo Provides the baseline description ("As-Is") that will evolve into a "To-Be" model as improvement concepts are developed, proved out, and integrated into the design.

- o **Analytic Tools**

Function Modeling Method ($IDEF_0$)

Information Modeling Method ($IDEF_1$)

Dynamic Modeling Method

ICAM Decision Support System ($IDEF_2$/ IDDSS2.0)
(Computer-based simulation system for exercising $IDEF_2$ model)

Interim AUTOIDEF

ICAM LIFE CYCLE STEPS

UNDERSTAND THE PROBLEM

1. ANALYZE NEEDS
2. ESTABLISH REQUIREMENTS DEFINITION

FORMULATE AND JUSTIFY SOLUTION

3. PERFORM PRELIMINARY DESIGN
4. PERFORM DETAIL DESIGN

CONSTRUCT, INTEGRATE AND TEST

5. CONSTRUCT, VERIFY AND TEST
6. INTEGRATE, VALIDATE AND TEST

IMPLEMENT AND MAINTAIN

7. IMPLEMENT AND USE
8. MAINTAIN AND SUPPORT

B. BATTELLE STUDY OF OKLAHOMA ENGINE REPAIR FACILITY

INTRODUCTION

The ICAM Approach

Beginning in 1976, the U.S. Air Force launched a program intended to help American industry improve productivity through the systematic application of computer technology to the problems of manufacturing. This program is called ICAM: Integrated Computer Aided Manufacturing. The ICAM approach provides a system of proven and demonstrated tools and techniques to help define, conduct, and monitor CAD/CAM projects. The approach provides (1) a means for communication between management and technical people, and (2) a procedure to insure that capital funds are spent on the best possible project. Procedure and language are among the tools and techniques of the ICAM approach. The procedure is found in the systematic sequence of events called the ICAM Life Cycle. The language is found in the methodology called the ICAM Definition Language (IDEF).

The ICAM Life Cycle consists of a sequence of top-down planning steps through a model, or architecture of manufacturing, and bottom-up implementation of individual subsystems. The objective is planning and organization of bottom-up development of subsystems that can be integrated ultimately into one manageable system to produce maximum benefits.

The ICAM Life Cycle consists of four major and eight minor steps as shown below:

Understand the Problem	Needs Analysis
	Requirements Definition
Formulate the Solution	Preliminary Design
	Detailed Design
Build the Solution	Construction and Verification
	Integration and Validation
Implement the Solution	Implementation and User Acceptance
	Maintenance and Support

The following sections briefly describe the content of the first step, "Understand the Problem," which is the subject of the four volumes of this report.

ICAM Step 1
Understand the Problem

In this contract the "problem" to be understood is the Engine Repair Facility at OC-ALC. Specific areas of operations which require detailed understanding include:

- Technical specifications for gas turbine engine repair
- Technology of repair processes in the ERF
- Resources available in the ERF
- Characteristics and projections of the workload
- Characteristics of the ERF organization
- Management practices
- Information and data requirements
- Relationships of the ERF to external organizations.

In the ICAM Definition Language these and other areas of interest are grouped in five categories, namely:

- Controls and constraints
- Inputs
- Outputs
- Resources
- Functions.

Understanding of these five important areas are obtained through the data collection activities of the two minor steps of ICAM step one, i.e., the analysis of needs and the definition of requirements.

Needs Analysis

Analysis of needs is the initial activity in a development program. The objective is to establish goals of the "To-Be" system by describing at a high level, areas to be impacted, system capabilities, costs, benefits, and expected return on investment. The Needs Analysis provides a high-level statement of constraints to which the new design must conform.

Requirements Definition

The Requirements Definition step provides descriptions of the existing or "As-Is" operation. Description is in the form of (1) models in the IDEF language which illustrate the operation from three different points of view, (2) review of the state of the art of existing as well as needed technologies, and (3) concepts for improvement of systems and subsystems.

The IDEF models of the "Understand the Problem" step are composed in two contexts, i.e., factory view and composite view models. The factory view models represent the present conditions in the operation being studied. The composite view models represent a synthesis of the operation being studied with other similar operations of cooperating subcontractors and others. Models in each of these two contexts take the following three specific forms:

$\underline{\text{IDEF}_0\text{-Function Model}}$. The function model provides a hierarchical description of the manufacturing operation in terms of the activities or functions which take place. It also shows the objects and information input to the function, the output from the function, the controls upon the function, and the mechanisms or resources which perform the function. A graphical methodology is employed to illustrate the movement of objects and data and sequence of functions. Each model is supported by text and glossary to provide further detail to the graphical description. By further graphical illustrations, each function can be decomposed to any extent to provide necessary levels of detail.

IDEF$_1$ -Information Model. The information model provides a different viewpoint of the operation being understood. This model focuses on the structure and interrelationships among the information which support the functions being performed. A graphical methodology is used to illustrate the relationships among entity classes of information which have common attributes. Pages of text support the diagrams with definitions of the content of entity classes and attributes.

IDEF$_2$ -Dynamic Model. The dynamic model presents a third viewpoint of the manufacturing operation. This model shows the time and sequence dependent characteristics of the operation. It serves as a way to analyze the interaction of functions and information over time, and is essentially a process flow diagram. The IDEF$_2$ graphical methodology provides an illustration of the operation and serves as a framework for accumulation of data to facilitate system simulation.

The second important activity of the Requirements Definition step is a review of the state of the art of existing (as-is operation) technologies as well as of needed (to-be operation) technologies. The state-of-the-art review broadens the perspective of the program team regarding the as-is operation, its functions and enabling technologies and resources. The review extends to (1) vendors of commercial equipment to facilitate the as-is functions, (2) practitioners of the functions and technologies in other similar manufacturing operations, and (3) recognized experts in the as-is needed technologies from the academic and research and development sectors.

An important output of the state-of-the-art review is the identification of technology voids. These are areas where the commercial offerings or the technological capabilities of the academic and R&D sectors do not support required improvement and integration of the as-is operations into a computer-aided manufacturing concept. Technology voids identify constraints upon progress or targets for research and development.

The third important activity of the Requirements Definition step is the identification of improvement concepts for the operations being understood. Improvement concepts can take many forms including:

- Physical or sequential rearrangement of functions
- Introduction of different but familiar technologies
- Development of novel technological approaches or machinery
- Integration of functional subsystems by development of coordinating hardware and software.

Improvement concepts might be described at a high level by textual descriptions of ideas or references to commercial literature.

A final activity of the Requirements Definition step is computer simulation of the As-Is Dynamic Factory Model. Simulation offers an opportunity to observe relationships of the time-dependent characteristics of the as-is operation and to introduce new conditions of workload, constraints, and variables. Several software tools are available to facilitate simulation based on the $IDEF_2$ models. An initial simulation package, ICAM Decision Support System (IDSS) Version 1, was developed by Hughes and is an on-line system designed to simulate manufacturing processes. This system is based on a generalized function model which uses process flow diagrams to describe the processes being simulated. IDSS Version 1 provides a language for the expression of systems, a data base for capturing and maintaining a system concept and a simulation capability for performing systems analysis. IDSS Version 1 can be executed interactively by communicating with a host computer via a terminal. Currently, IDSS Version 1 is hosted on CYBERNET, a network supported by the Control Data Corporation.

A more recently implemented simulation system which extended the concepts of IDSS Version 1 is entitled ICAM Decision Support System, Prototype (2.0), hereafter denoted IDSS 2.0. IDSS 2.0, developed by Pritsker & Associates, was completed around March, 1982. It consists of an interactive software system which directs a user in performing each of the following four tasks: Model Build, Translation, Run and Output. $IDEF_2$ Models are developed entirely at a graphics terminal or teletype. Model translation and simulation are performed automatically.

This Program
Manufacturing Technology For Gas Turbine Engine Repair Center OC-ALC

This ICAM life cycle is being employed on this program to provide

- A detailed model of blade repair activities both in the "as-is" and "to-be" forms
- A high level model of the Engine Repair Facility (ERF) at OC-ALC for future planning and integration
- A simulation model of the high level ERF to provide a management tool for allocating resources and establishing entity flows
- Detail design, construction, and implementation of an Integrated Welding and Grinding (IWAG) cell and subsequently, an Integrared Blade Repair Center (IBRC).

While the time constraints imposed by the contract on this program did not fully allow the natural flow for the ICAM life cycle (immediate progress in turbine blade welding and grinding was required), nevertheless, Battelle feels that the approach is valuable. Sufficient information has been recorded to provide integration means for bottom-up implementation of the improvements recommended for the Engine Repair Facility and its subsystems.

Battelle also feels that the application of this ICAM approach can be extended to other government and private sector industries for use in implementation of advanced technology. The knowledge gained during the application of the ICAM methodology at OC-ALC indicates that

- This disciplined approach to examining and documenting a manufacturing system can provide a thorough understanding of complex processes
- The results of the examination can provide a "roadmap" for future integrated improvements
- The information collected can serve as a firm basis for the design and implementation of these integrated improvements.

OBJECTIVES

This Program

The overall objective of this program is to establish an ICAM architecture for the Oklahoma City Air Logistics Center (OC-ALC) Engine Repair Facility (ERF) for use, first in the design, construction, and implementation of an automated, integrated welding and grinding (IWAG) cell for repair of turbine blades, and second, in the design, construction, and implementation of an integrated blade repair center (IBRC).

To achieve this overall objective Step I of the ICAM approach provides for a sequence of specific activities. The stated objectives for each of these activities follow.

Needs Analysis

The primary objective in analyzing needs of the Engine Repair Facility (ERF) subsystems is to establish overall goals and directions for improvement of subsystems, to be developed during this and subsequent programs. Consistent with the overall program objective, the contract Statement of Work (SOW) identifies several candidate needs within the planned Integrated Blade Repair Center (IBRC) subsystem, to be given first priority in this program. The Phase I Needs Analysis Report addressed this requirement within the IBRC, identifying the needs of an Integrated Welding and Grinding (IWAG) cell and an associated Integrated Material Handling and Storage Subsystem (IMH/SS), merging the IWAG with an Integrated Blade Inspection Subsystem (IBIS). Additionally, the Phase I Report assessed the needs of an IBIS and two or three other IBRC modules.

In Phase II, the needs analysis methodology established in Phase I was applied to major subsystems of the Production Branch of the Propulsion Division and to other selected branches of the Directorate of Maintenance as interrelationships were perceived to be relevant. Included are specific analyses of all major functions of the BRC except those emphasized in Phase I.

As-Is Factory-View Models

The objective of building models representing the As-Is operations of the ERF in the ICAM Definition Language (IDEF) is to (1) document understanding of the present operations, (2) organize data relating to ERF operations, (3) identify modular areas for detailed study, (4) provide a base upon which to plan improvements, and (5) facilitate communication of functional relationships for orientation of additional specialist team members, as required.

Composite-View Models

The objective of building models representing the composite view of operations at OC-ALC, SA-ALC, and at several commercial engine repair facilities in the ICAM Definition Language (IDEF) is to (1) document understandings of variations of operational practices at the several plants studied, (2) organize data relating to the composite view, (3) identify functional relationships for functions not included in the As-Is Factory View Models, (4) broaden the base of information upon which to plan improvements, and (5) facilitate communication of functional relationships for orientation of additional specialist team members, as required.

State-of-the-Art Review

The objective of the State-of-the-Art (SOA) Review is to determine what equipment is commercially available to meet the technical needs of the ERF and BRC/IBRC* processes, functions, and subsystems and of the described improvement concepts. Needs are defined by (1) the Needs Analysis for as-is conditions within the ERF, (2) the projected FY85 work load, and (3) possible improvements described in the NA as well as by concepts described in the Improvement Concepts Section of this report.

Improvement Concepts Study

The objective of the Improvements Concept (IC) Study is to identify concepts with potential for improvement of the ERF and BRC/IBRC processes, functions, and subsystems. These concepts might represent commercial, technical alternatives to as-is practices, or approaches which may be beyond the state of the art, and might be novel assemblies of commercial subsystems requiring unique technological developments for integration.

Simulation of ERF As-Is Dynamic Factory Model

The objective of this activity is to provide a simulation model of the current ERF which depicts at a high level the flow of principal entities, primarily engines for major and minor overhaul, through the various ERF functions. The purpose of this model, in addition to validating the ERF IDEF Models, is to (1) provide useful input to capacity studies, (2) assist in determining the locations of bottlenecks, (3) assist in determining critical paths, and (4) provide a baseline model for future efforts such as preliminary ERF design.

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*BRC is used to denote the as-is Blade Repair Center. IBRC is Integrated Blade Repair Center and is used to denote the improved Blade Repair Center to be developed under this contract.

APPROACH

Accomplishment of the specific objectives of the several tasks of ICAM Step 1, Understand the Problem, is necessary ground work to achieve the overall objectives of the program. The approach taken to the Step 1 work follows closely the details of the ICAM plan.

A coalition of subcontractors was formed with several companies having expertise in the general fields of concern. Subcontractors and their principal roles are listed in the preface to this report. Battelle was further supported by representatives from OC-ALC and SA-ALC* Interview teams composed of experienced engineers, manufacturing specialists, and information and software specialists toured the ERF extensively, interviewing management and operating personnel at many levels. Data were collected, repair operations were observed, and IDEF models were constructed. Through many iterations as-is models were reviewed and refined. Data and verbal descriptions of functional operations were expanded to support the models.

Teams of interviewers toured other related industrial facilities to expand the data base and improve understanding of the problem. Engine repair facilities of SA-ALC and two commercial enterprises were toured and management and operating personnel were interviewed. Turbine engine blade production facilities and research facilities of other original equipment manufacturers were toured and further understanding was gained through interviews.

From the familiarity and understanding of engine repair operations gained through the tours, interviews, and data collection performed from October, 1980 through March, 1982, a detailed description of the operation of ERF subsystems is developed. This description forms a background for

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*SA-ALC: San Antonio Air Logistics Center

definition of problems and needs in the ERF subsystems and is developed into the Needs Analysis (NA) Report. This report was composed by Battelle staff members of the previously described data collection and interview teams. The NA identifies problems in the present conditions, and defines needs in terms of solutions to problems. Needs are prioritized and some possible improvements are described.

A state-of-the-art survey was started to acquire information regarding current commercial offerings of vendors in the technology fields of the ERF subsystems. Additionally, some specific technology fields were addressed because of their importance to integration of manufacturing systems, which will be of interest for development of improvement designs. Inquiries conducted by telephone surveys led to identification of other technologies or techniques for accomplishment of the needed functions. Improvement concepts suggested in a separate study of new technological approaches were referred to the state-of-the-art survey team as additional subjects for the survey. In this way a body of information was accumulated relating to enabling technologies for all as-is operations or improvement concepts. Through this SOA review technology voids were identified wherein there are weaknesses in the availability of commercial offerings or in the basic technology of manufacturing to support the improvements visualized for the ERF in this study.

In an effort parallel to the state-of-the-art review, an improvement concepts study was performed to address needs in the areas of technology voids, to introduce new technological approaches, or to visualize integrated subsystem approaches. These concepts are described in text and sketches at a high level.

The approach to the ERF simulation activity involves utilizing the Pritsker & Associates' prototype IDSS Version 2.0. The first phase of the approach includes developing a simple model of the ERF based on its six principal work centers. Once this model has been implemented and validated, plans are that a more complex model resulting from the decomposition of the six work centers into more detailed functions (possibly the individual activities of the 34 Resource Control Centers comprising the ERF) will be implemented. This detailed model would use as its basis the ERF $IDEF_2$ Model developed during Phase II.

SUMMARY OF RESULTS

Needs Analysis
(Vol. II)

The Needs Analysis covers all principal functions, processes, and subsystems of the ERF. In the NA Report 135 statements of need are defined, summarized, and prioritized. These needs can be further condensed into the following six generalized statements of need:

(1) Pursue equipmental and organizational improvements in the ERF operations and in its functions to support the IBRC concept and the philosophies of the ICAM program.

(2) Study the problem of high engine test failure rate in the many ERF functions which potentially contribute to the problem, including disassembly, inspection, machining, rotor kitting, assembly, and balance, engine assembly, test, and the penalty line function.

(3) Automate/computerize ERF production management and scheduling.

(4) Enhance consideration for safety and human factors in all operations.

(5) Improve product quality while reducing production costs through modernization, integration, and computerization of equipment resources and procedures.

(6) Emphasize and expand employee development programs and policies to address modern requirements for management, technology, and maintenance.

Possible improvements to achieve benefits in these areas of need are suggested in the form of modern techniques, commercial equipment, or concepts for unique, special purpose equipment systems.

As-Is Factory-View Models
[Vols. III (1-9)]

As-Is factory-view models were constructed to represent the operations of the ERF and Blade Repair Center (BRC). Models include Function ($IDEF_0$), Information ($IDEF_1$), and Dynamic ($IDEF_2$) models for the ERF and Dynamic ($IDEF_2$) models for both turbine and compressor blades in the BRC. The models are developed only to a level necessary to provide understanding of the functions and functional relationships, and to organize accumulated data. The models provide the expected sound base of understanding required to support further planning of improvements for the ERF and BRC/IBRC.

Composite-View Models
[Vols. III (6-8)]

Composite-view models were constructed to incorporate functional practices of subcontractors and other engine repair contributors into the descriptions of operations of the ERF and BRC. Models include a Function ($IDEF_0$) model for the ERF and Information and Dynamic Models ($IDEF_1$ and $IDEF_2$ respectively) for the BRC. These models are developed only to a level necessary to provide understanding of the functions and differences, and to organize accumulated data. The models provide the expected sound base of understanding required to support further planning of improvements for the ERF and BRC/IBRC.

State-of-the-Art Review
(Vol. III-9)

The State-of-the-Art Review provides a broad base of understanding of current offerings of commercial equipment vendors and the capabilities of these products to meet needs of the ERF. Important product data has been accumulated and organized for use in defining improvement designs. The study includes discussions of functions or technologies introduced through the composite models or through concepts suggested in the Improvement Concepts Study.

The SOA Review report also identifies five areas of technology voids and describes details of the need and conditions for developing the needed technologies.

Improvement Concepts Study (Vol. III-9)

The Improvement Concepts Study provides an additional dimension of understanding of the problem. Concepts for improvement of ERF and BRC processes are described in those areas where commercial offerings do not acceptably address the needs. Some of the concepts represent definite steps forward beyond the state of the art being, to an extent, creative research and development even though based on sound and familiar physical principles. Other concepts represent transfer of technology from other industrial operations or unique integration of familiar technology.

Simulation of ERF As-Is Dynamic Factory Model (Vol. IV)

The ERF Dynamic Factory Model ($IDEF_2$) was developed at a high level to facilitate computer simulation. This portion of the project is ongoing. Results of this activity will be reported upon completion in Simulation of ERF As-Is Dynamic Factory Model (High Level) Volume IV.

CONCLUSIONS

Many important conclusions are drawn at detail levels from the work performed which are described in other volumes of this set. These detail level conclusions are not repeated here because they are too numerous. Detailed study of other volumes of this set is recommended to the reader as individual needs or interests may direct. High level conclusions only are provided in the following.

(1) The ICAM approach provides an effective methodology to accomplish the objectives of the "Understand the Problem" step.

(2) The studies reported in the volumes of this set provide important, detailed documentation for understanding the problems of engine remanufacturing, of the ERF operations, and of the status of technologies of the ERF functions.

(3) The findings reported in the volumes of this set, in many cases represent perceptions and opinions of the Battelle study team. However, these findings have been extensively reviewed by contributors at OC-ALC, SA-ALC, and by members of the coalition of subcontractors, and other volunteer industrial leaders to assure relevant and realistic viewpoints.

(4) Substantial gains in all areas of benefits expected in this program can be derived by systematic planning and development of improvements along the lines suggested in this report.

(5) Accumulated data in the volumes of this set and in the library files of the Battelle Program Office provide an important base for planning preliminary and detail design phases for subsystem improvements.

(6) Some needs and recommended improvements are identified which are outside of the Production Branch of the Propulsion Division but which impact upon production.

RECOMMENDATIONS

Based on the work performed and the conclusions drawn from that work, Battelle recommends the following action plan for improvement of the ERF operations at OC-ALC.

(1) Current OC-ALC plans for improvement should be reviewed to provide for incorporating specific subsystem improvement as defined in this study on a prioritized basis.

(2) Details of needs and possible improvements outlined in this study should be reviewed and prioritized in preliminary and detail design plans for ERF and IBRC operations as provided for in this program as well as in other programs.

(3) Exploratory programs should be considered in those technical areas identified as technology voids to extend the state of the art in needed technologies. Additionally, new developments in these areas should be monitored to maintain continuing assessment of the state of the art.

C. $IDEF_1$- INTRODUCTION

$IDEF_1$ was developed as a part of an overall program for Integrated Computer Aided Manufacturing (ICAM) sponsored by the U.S. Air Force. The ICAM program is geared toward the improvement of aerospace manufacturing productivity through the use of computers. The $IDEF_1$ technique focues on the understanding of information in the manufacturing environment; it results in a precise and comprehensive representation of the integrated structural aspects of information within some portion of the manufacturing enterprise.

$IDEF_1$ is one of three vital new requirements modeling tools developed under the ICAM program. Taken together, these are called the ICAM Definition Method (hence the acronym IDEF). Each is a language designed to be used in understanding some aspect of the manufacturing enterprise. The three tools are:

- $IDEF_0$- a language that deals with the functional aspects of a manufacturing environment, and the ways in which these are inter-dependent.

- $IDEF_1$- a language that deals with the information aspects of a manufacturing environment, and the interrelationships of information components.

o IDEF$_2$- a language that deals with the dynamic aspects of a manufacturing environment having to do with the movement of objects and information.

The need for the ICAM program and the IDEF$_1$ techniques became clear as the difficulty in designing integrated manufacturing systems became more and more apparent. Controlling and coordinating integration of manufacturing information often appears virtually impossible. Manufacturing oeprations tend to be so diverse that the real requirements to be placed on an integration effort are simply "buried" in all the complexity.

Hence, the ICAM program. And from it, the IDEF$_1$ technique of information modeling. From an extensive and detailed examination of available manufacturing and engineering practices and the kinds of problems cited above, it was concluded that the most practical way to approach the problem of integration of manufacturing information was to develop an information requirements model prior to designing and building the corresponding information system. The IDEF$_1$ technique for developing such models was designed to reflect the integration of manufacturing information within the overall manufacturing enterprise. The ICAM approach is, then, to:

1. first, build an integrated information model;

2. next, design a database(s) from the information model;

3. finally, implement and install the database(s) and associated functional and procedural components.

The $IDEF_1$ technique offers a set of rules and procedures for creating information models. It incorporates the necessary graphics, text, and forms to inject an organized discipline into the process. It provides for the measurement and control of the progress development of the model through the routine of the modeling discipline.

Because the modeling discipline involves an evolutionary process, it is organized into stages with measurable results and specific products. It develops toward a more exact definition with each iteration. It provides a modularity, both in its practice and product, that cannot be found in other methods, and that protects against the inaccuracies, incompleteness, inconsistency, and imprecision so often encountered.

There are two fundamental components of an information model:

1. Diagrams: the structural characteristics of the information model, displayed in accordance with a set of rules and procedures that construct a meaningful representation information.

2. Dictionary: the meaning of each element of the model reflected through the compendium of text and indexes that clearly define the information reflected in the model.

An $IDEF_1$ model involves the entire manufacturing organization. There are several roles that have to be fulfilled to conduct a successful modeling effort. This model is principally geared toward the benefit of the

Modeler, or "recorder" of the model. The Modeler's teammates are: the Project Manager; the Source(s); the Reviewer(s); and the Review Committee.

The Modeler is a modeling expert. The employment of the techniques, the maintenance of the momentum, the organization and publication of data, and, in general, the production of the model are the responsibility of the Modeler. The shape of the informtion structure of a manufacturing activity (its architecture) as represented in the model, is the primary responsibility of the other team members.

An $IDEF_1$ information model, then, is a reflection of the total manufacturing enterprise, and provides a baseline definition of that organization's informational needs. It ensures that the information can be shared, and that the information system of the total enterprise is, in fact, integrated.

$IDEF_1$ is a new technique that addresses the many problems cited above with a structured, broad-based fresh approach. An information model is an attempt to determine "what is needed" in terms of information, for a manufacturing enterprise, and to represent this graphically as modular units of detail. An information model provides a precise, accurate, and concise description of the information needed by a manufacturing enterprise. In addition, the information model has a formal character, which provides for a precise understanding of the information it portrays. And finally, an information model is a tool that has practical value whether or not the manufacturing enterprise is heavily committed to the use of computers; but optimum value to the enterprise struggling with the problem of integrated system design.

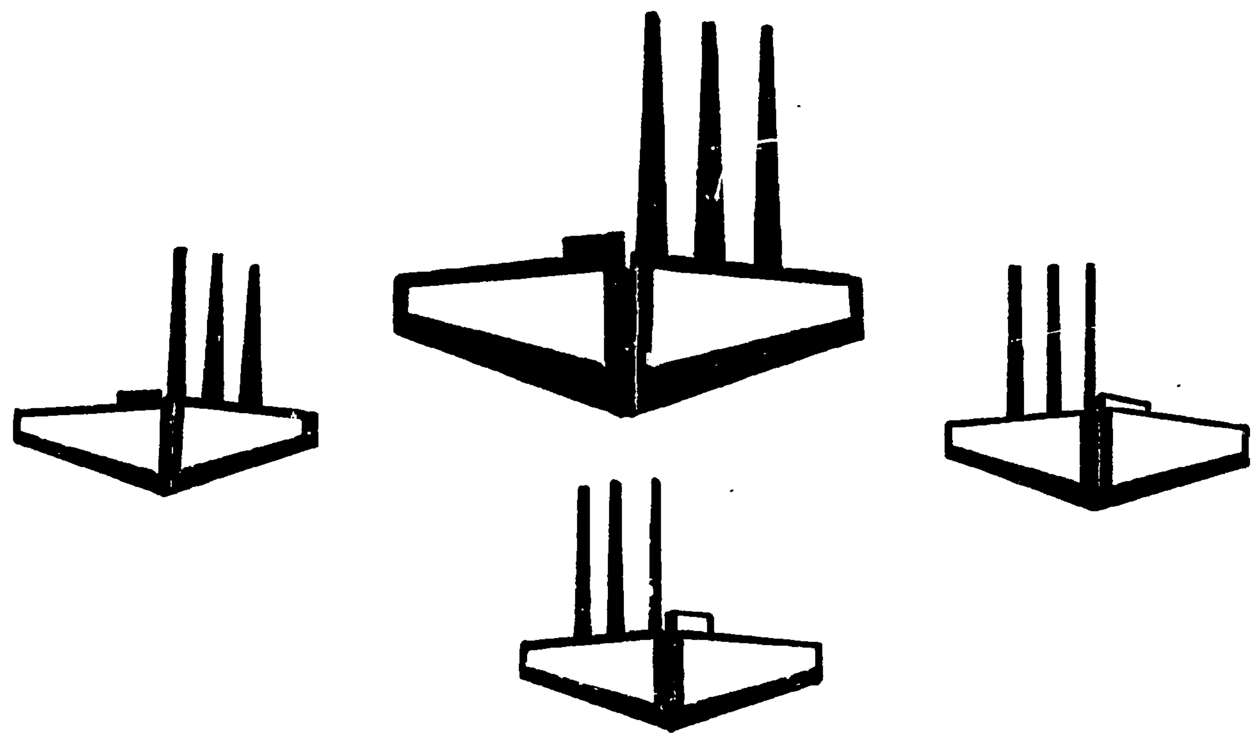
HOW CAN $IDEF_0$ HELP THE MANAGER?

$IDEF_0$ permits the manager to:

- Systematically analyze a program objective into the hierarchy of tasks (activities, functions) required to accomplish the objective
- Define the interrelationships among tasks
- Define the inputs and outputs required for each task
- Define constraints (controls) that act on a given activity
- Indicate the use of feedback to modify earlier activities
- Create a work breakdown structure (WBS)
- Use the WBS to assign work and to identify required resources
- Communicate this plan unambiguously, using a standard set of symbols, meanings associated with the symbols, and rules for using the symbols

ICAM

IDEF → ARCHITECTURE



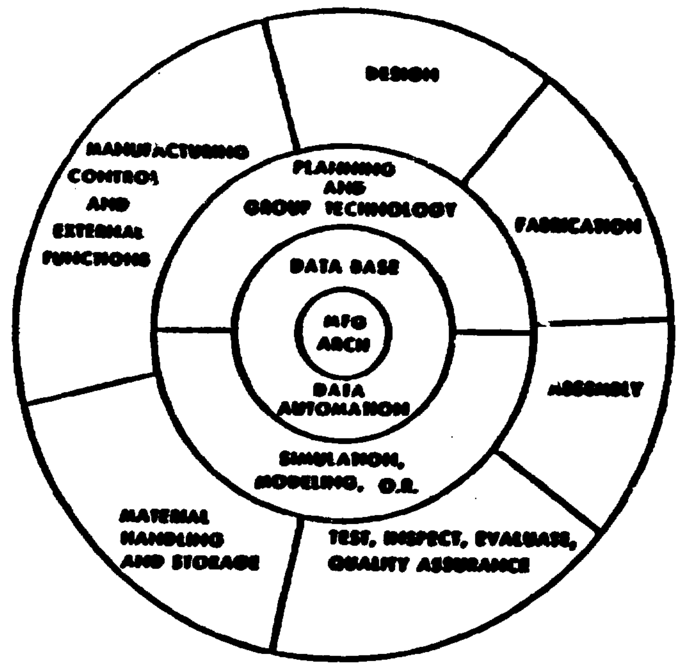
IDEF → ARCHITECTURE

- ***WHAT IS ICAM ?***
- ***WHAT IS IDEF ?***
- ***HOW DOES IDEF RELATE TO ARCHITECTURE ?***

WHAT IS ICAM?

ICAM

INTEGRATED COMPUTER-AIDED MANUFACTURING



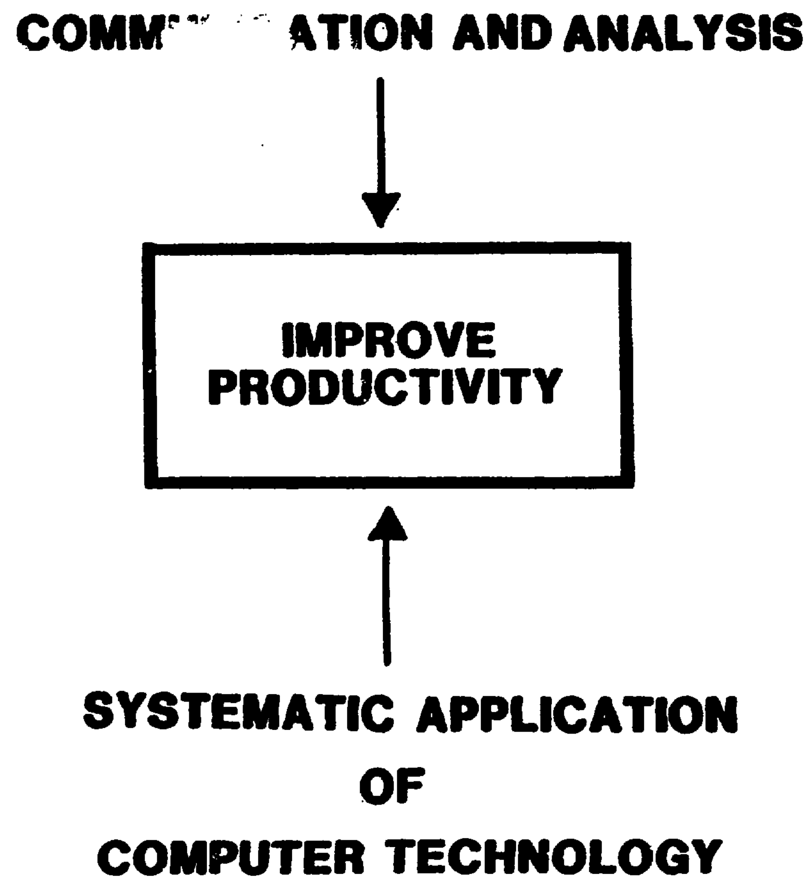
PURPOSE OF ICAM

IMPROVE PRODUCTIVITY

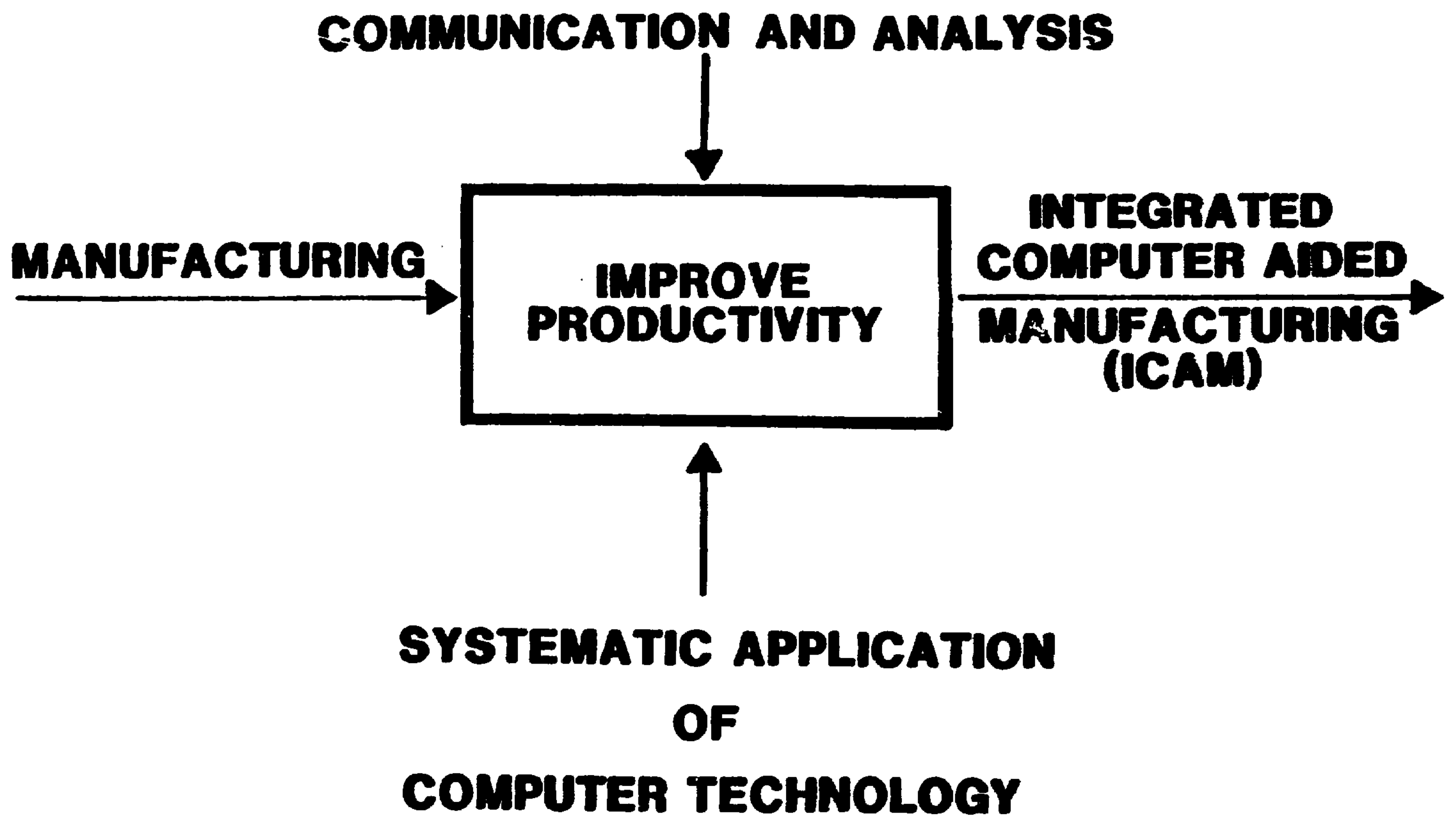
↑

SYSTEMATIC APPLICATION OF COMPUTER TECHNOLOGY

ICAM APPROACH

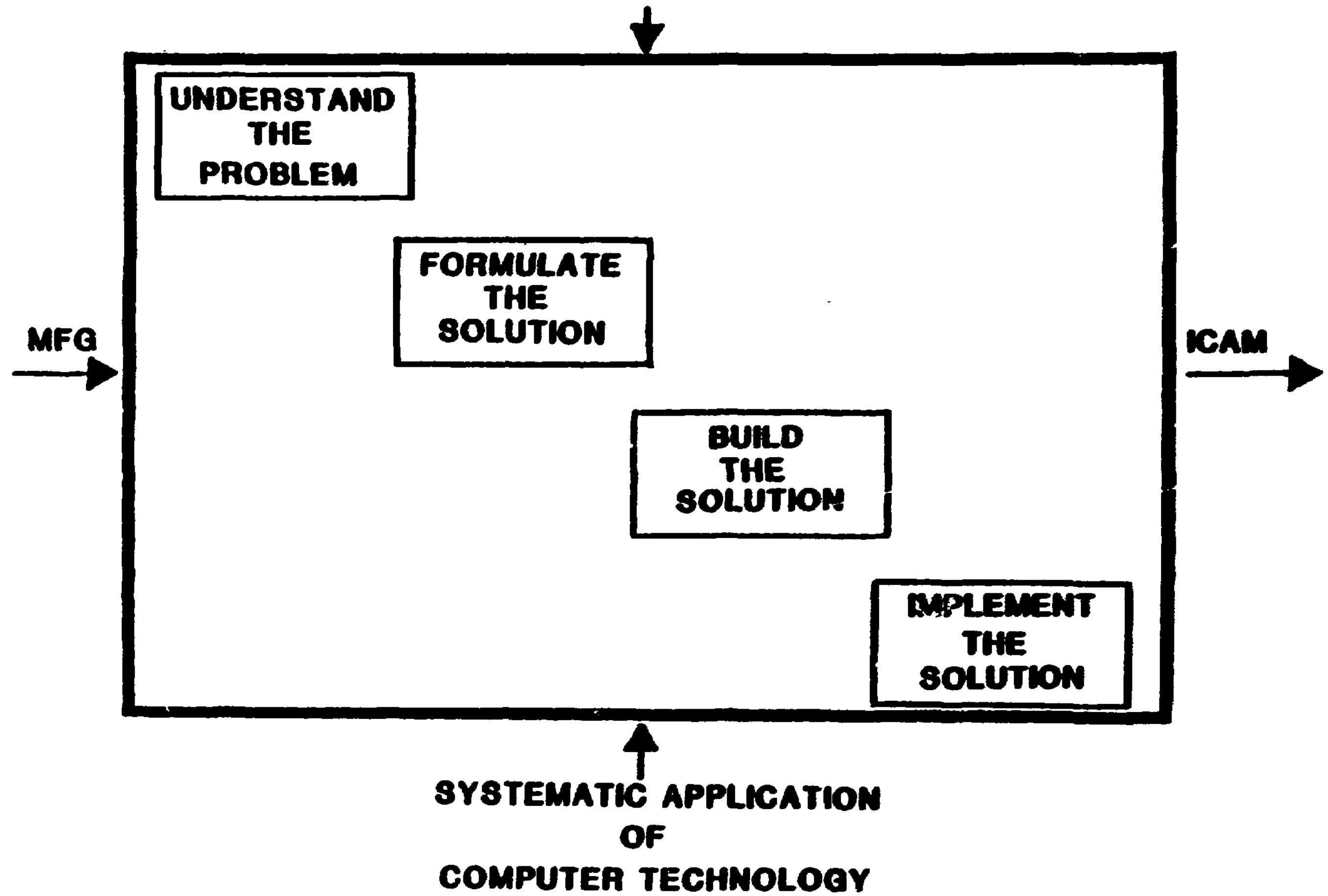


OBJECTIVE OF ICAM

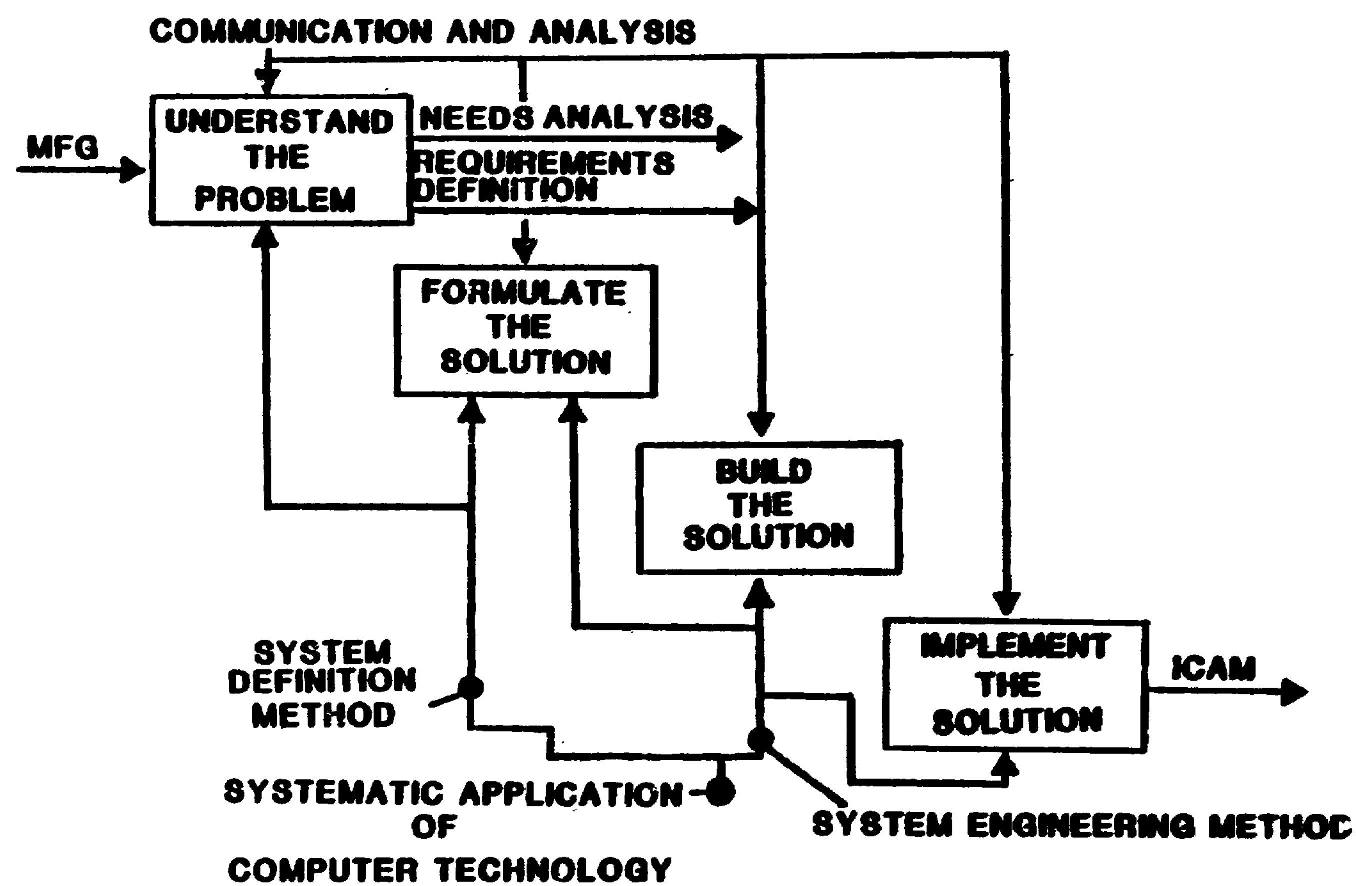


IMPROVE PRODUCTIVITY

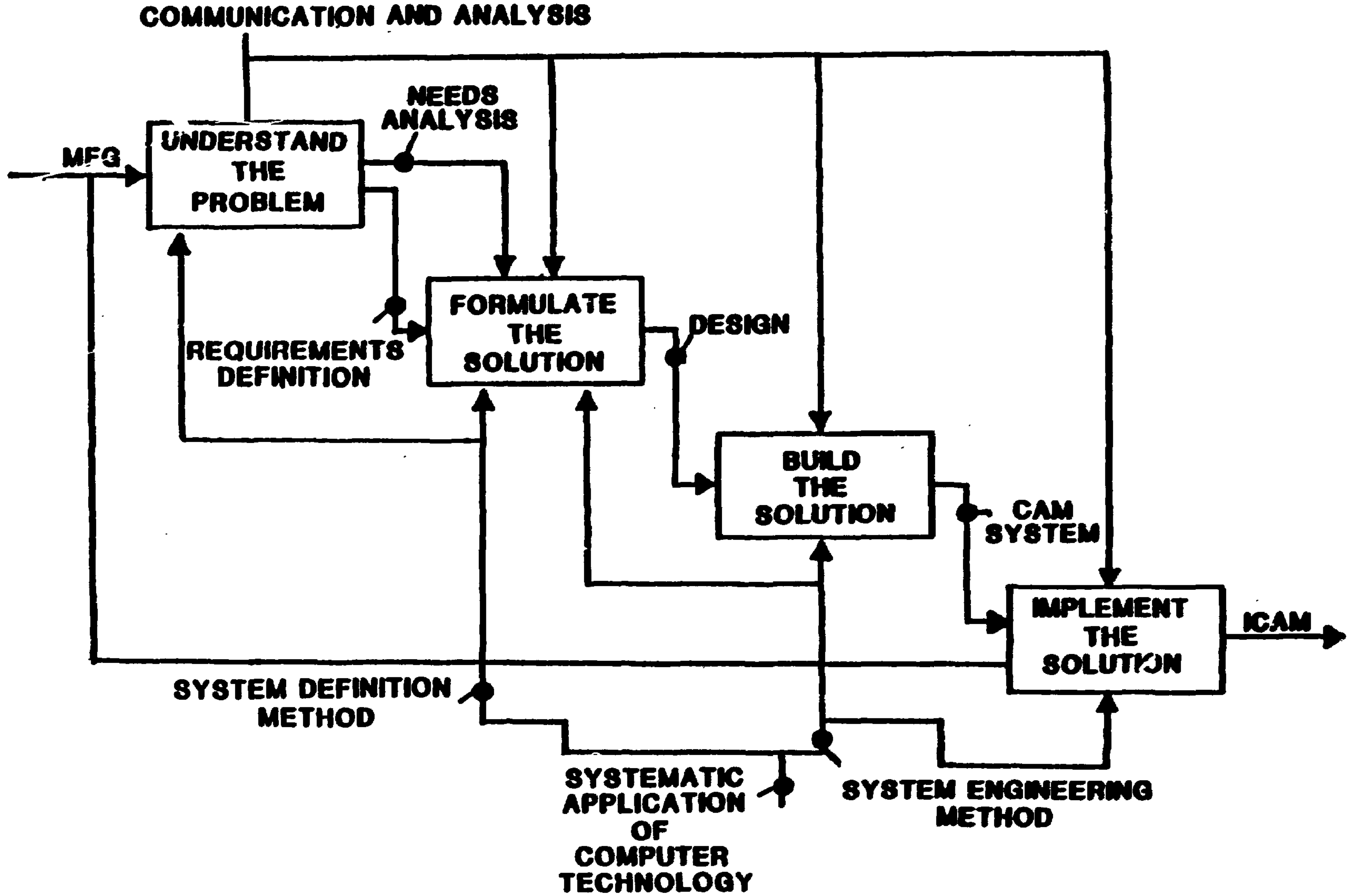
COMMUNICATION AND ANALYSIS



IMPROVE PRODUCTIVITY



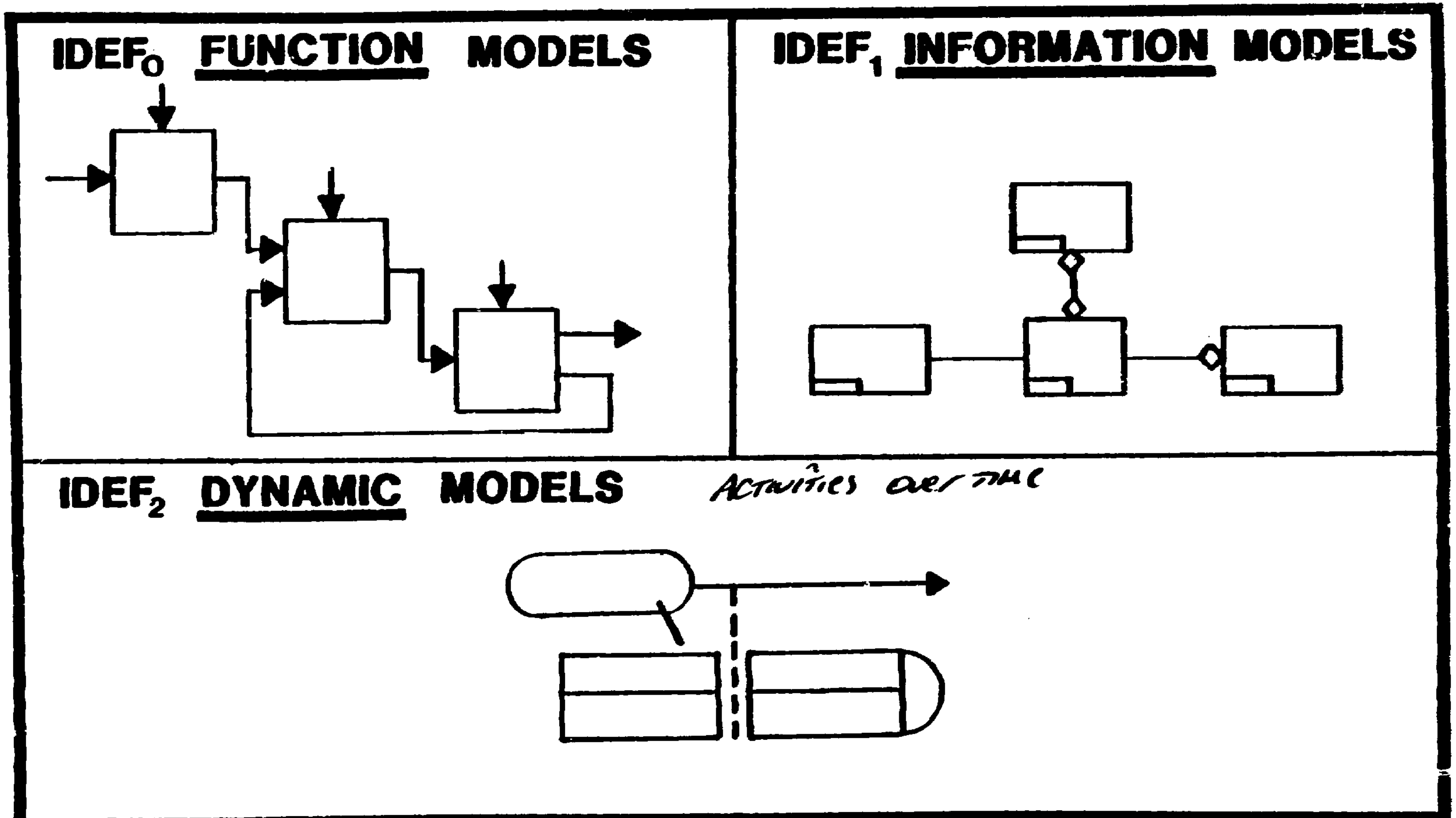
IMPROVE PRODUCTIVITY



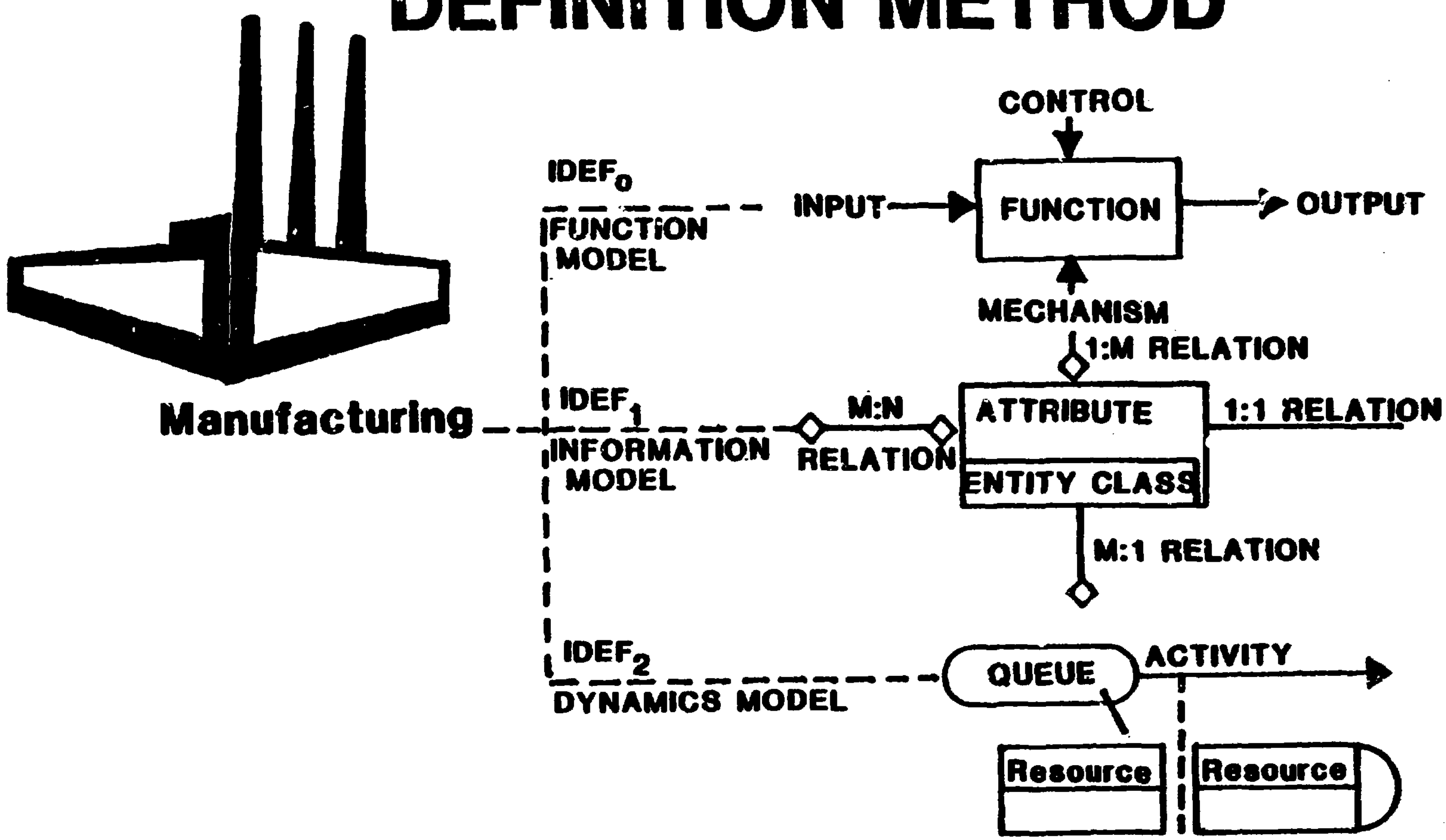
WHAT IS IDEF?

ICAM DEFINITION ➛ IDEF

SYSTEMATIC APPLICATION of COMPUTER TECHNOLOGY



IDEF - A SYSTEM DEFINITION METHOD



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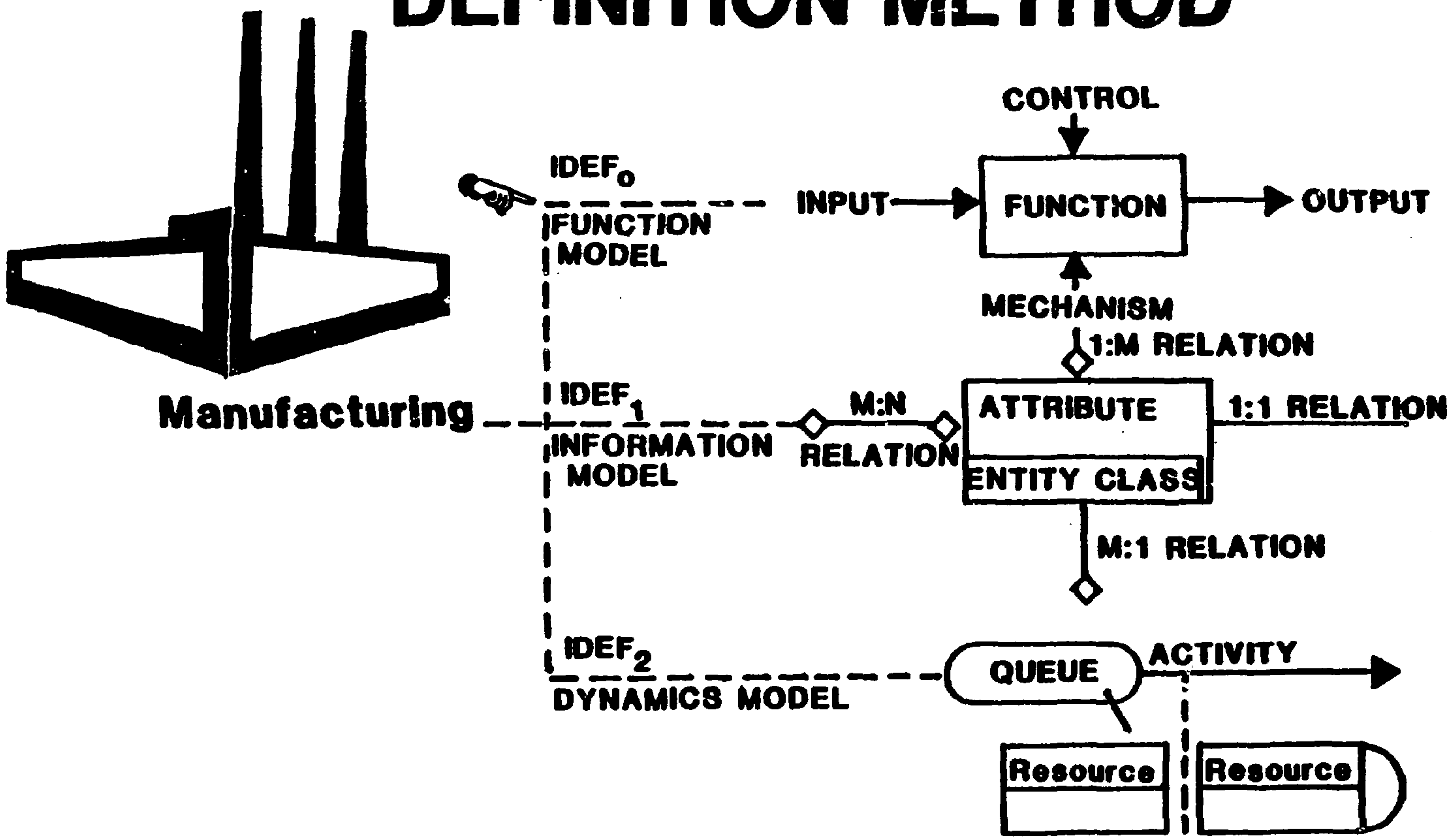
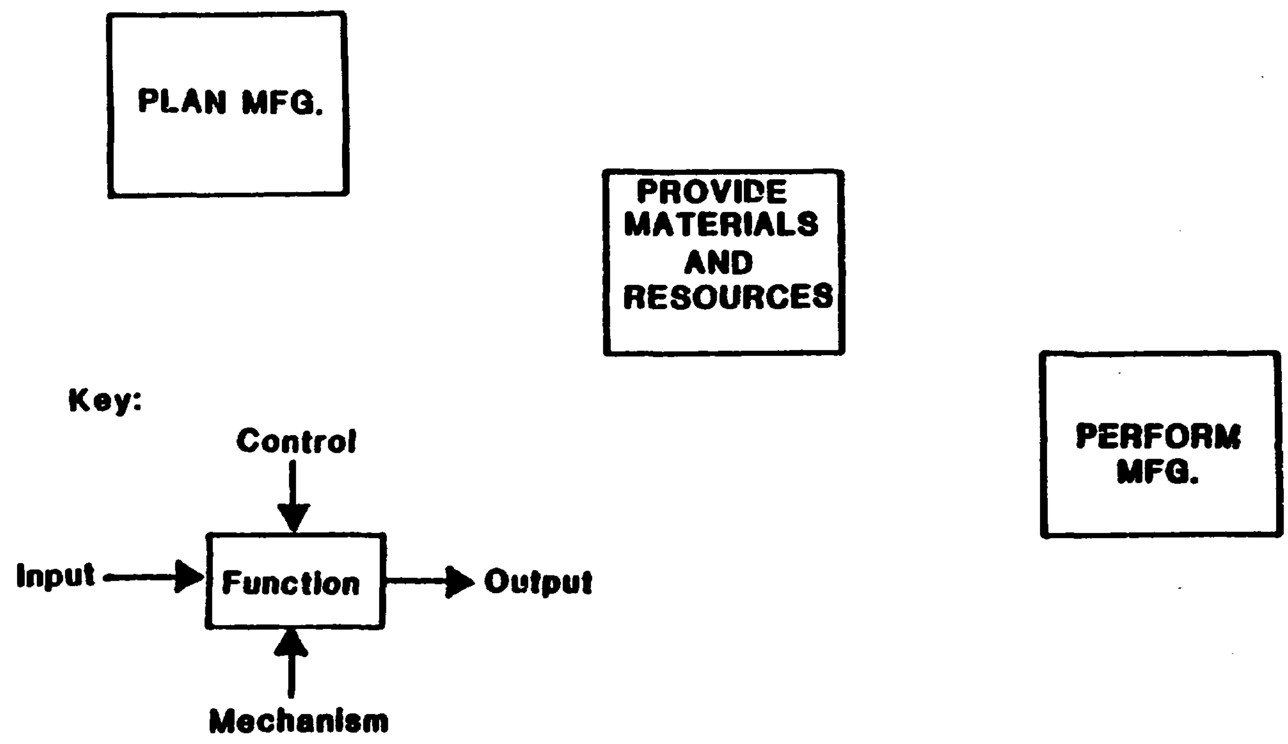


IDEF$_0$ → FUNCTION MODEL



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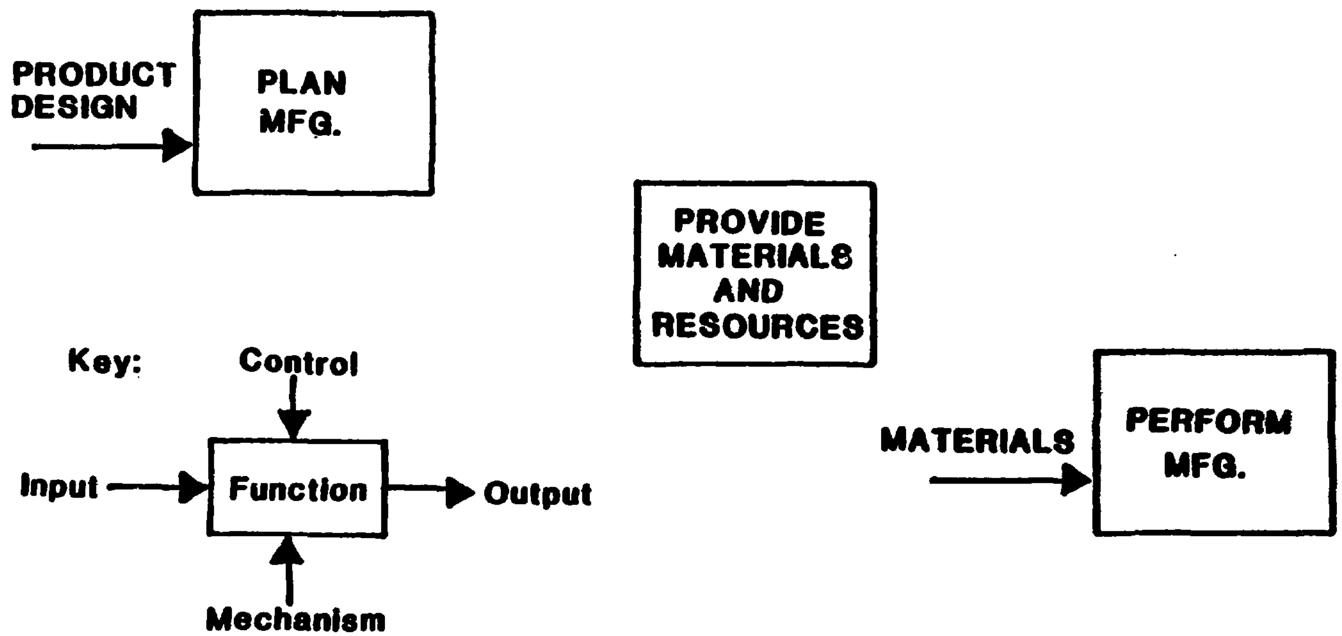

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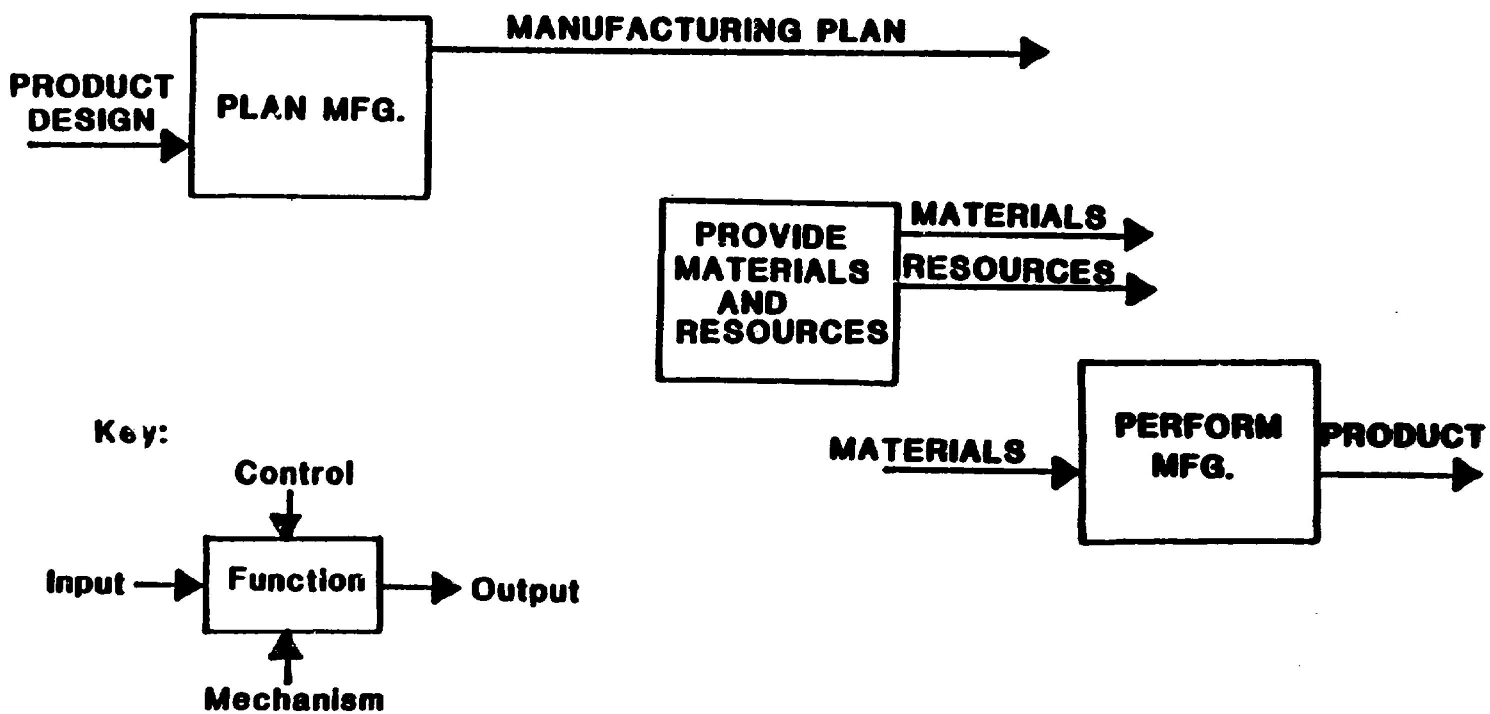

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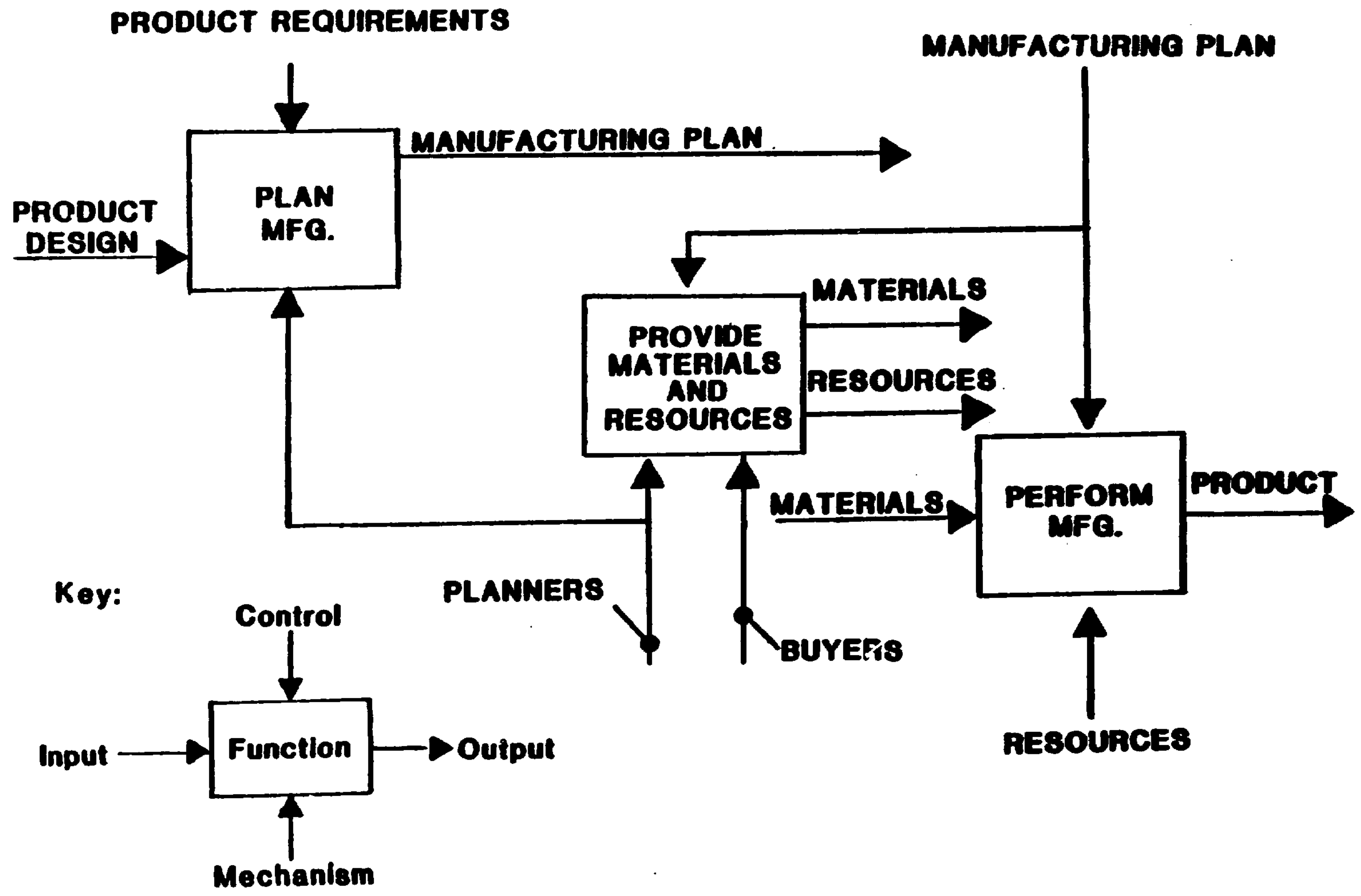

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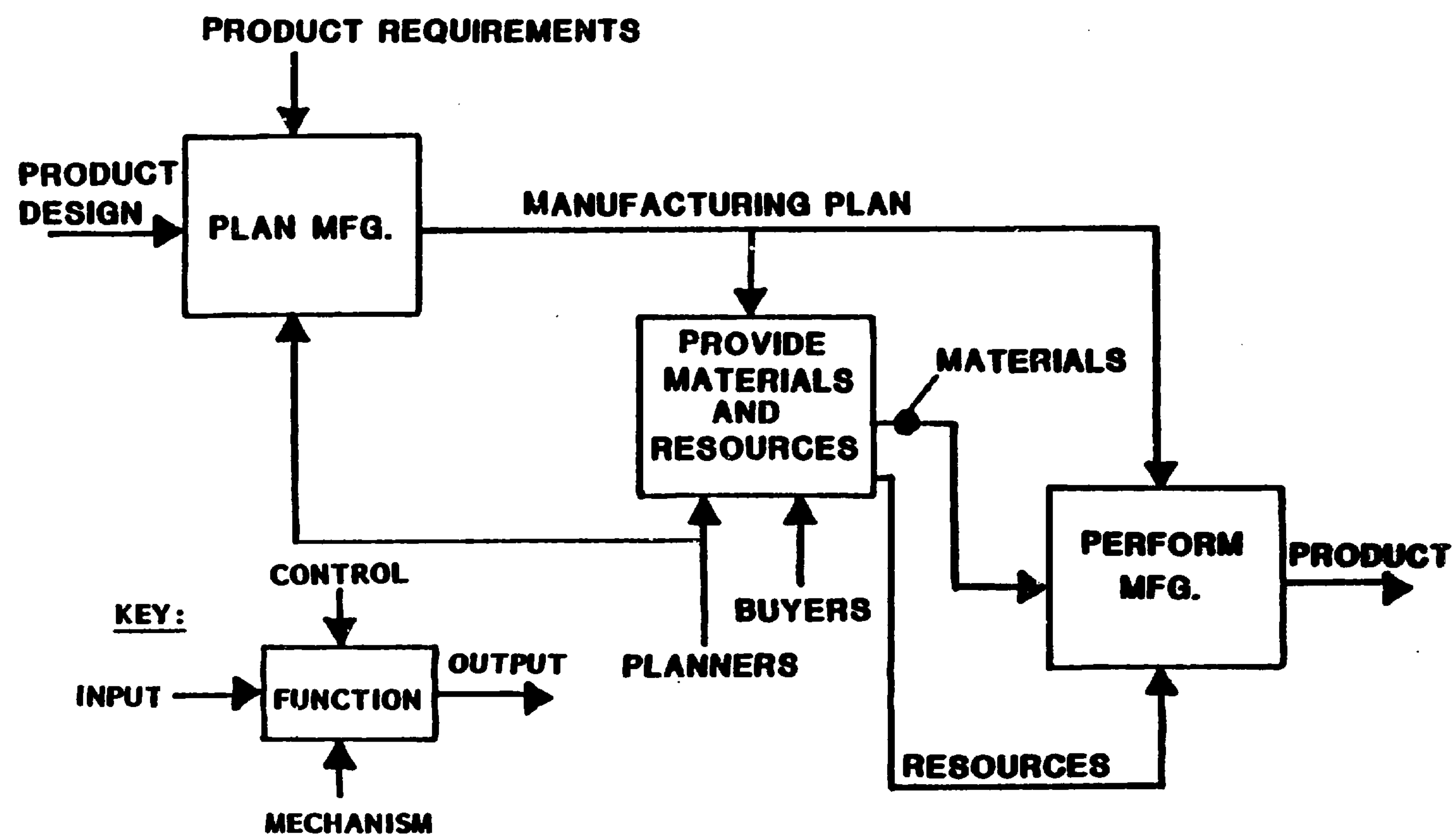
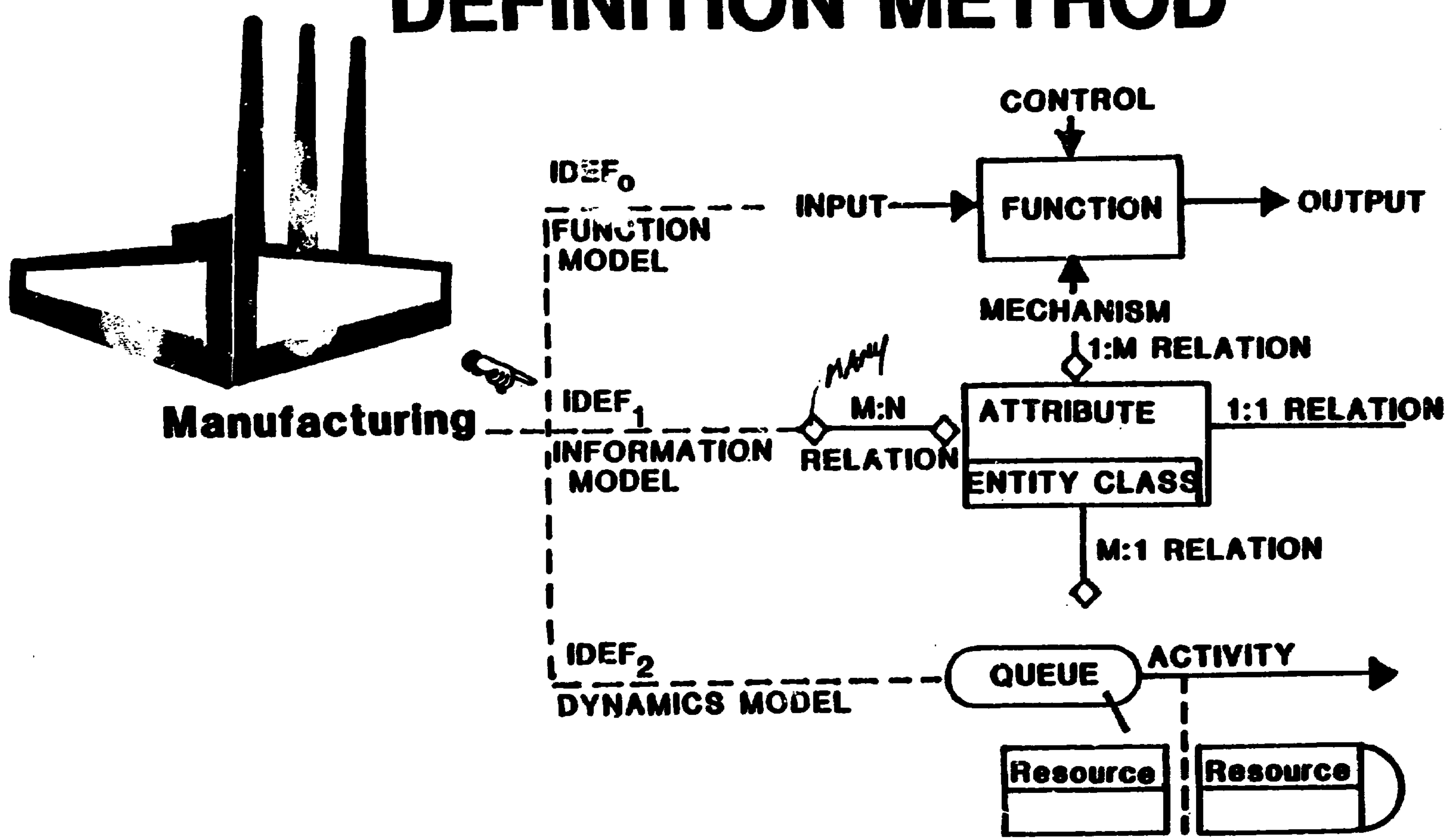
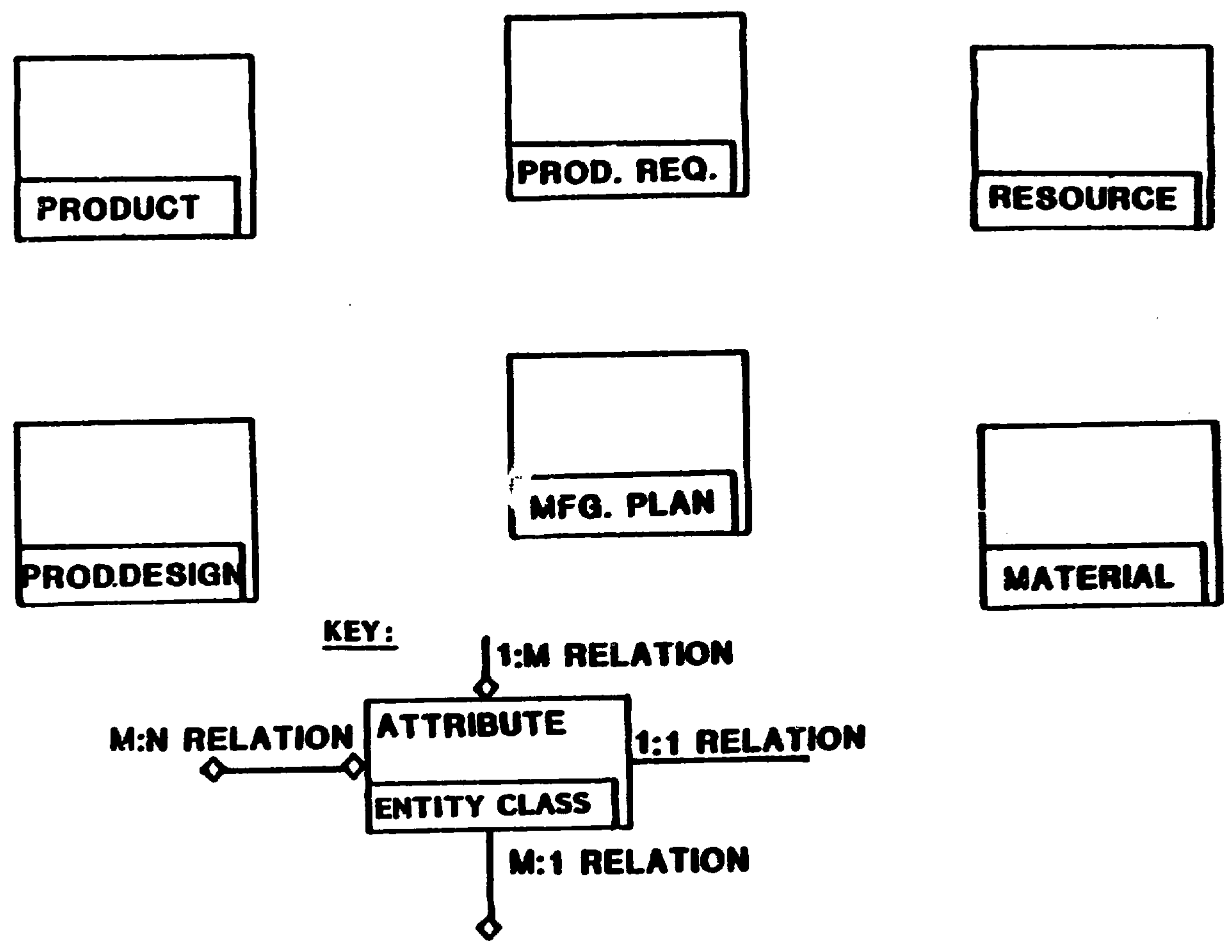


IDEF - A SYSTEM DEFINITION METHOD



IDEF$_1$ → INFORMATION MODEL



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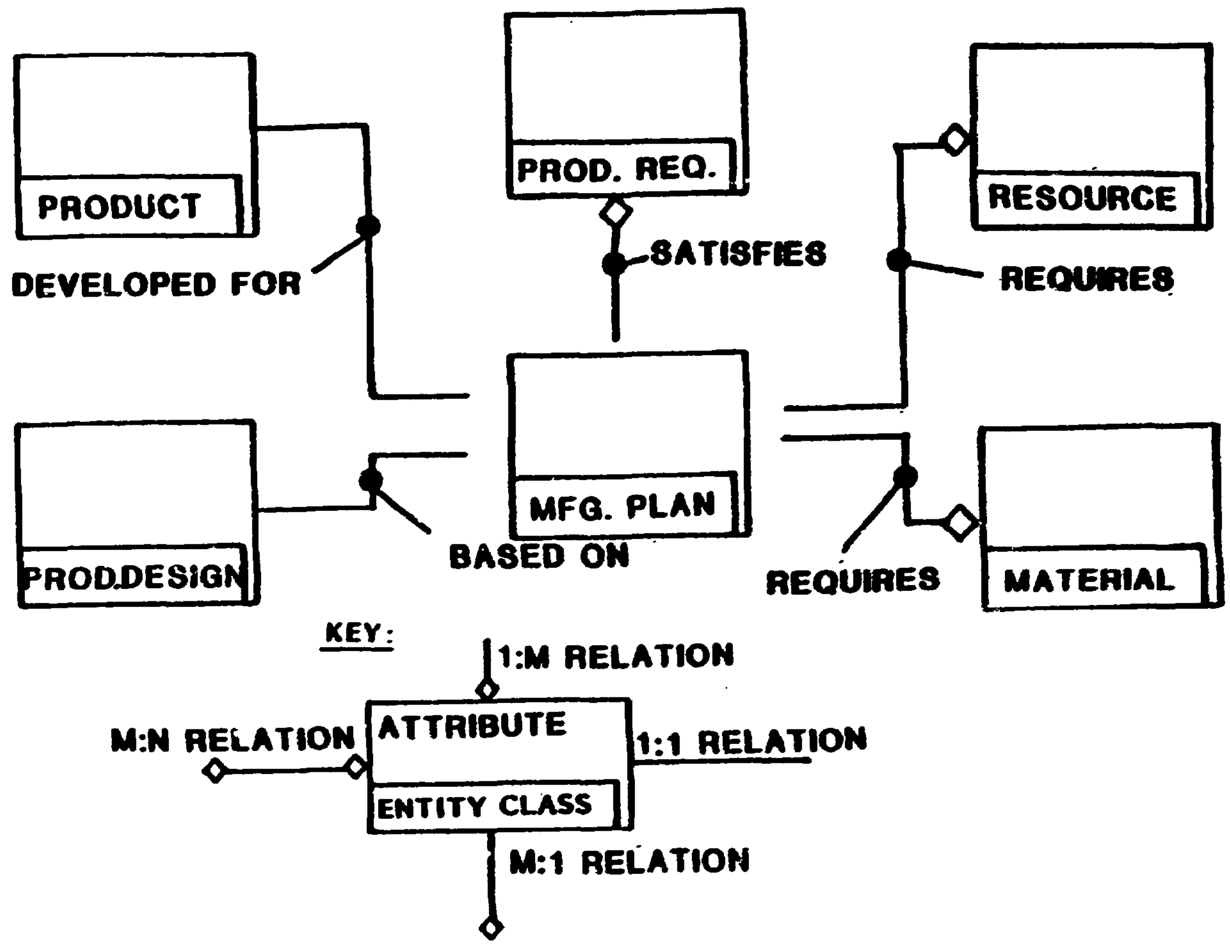
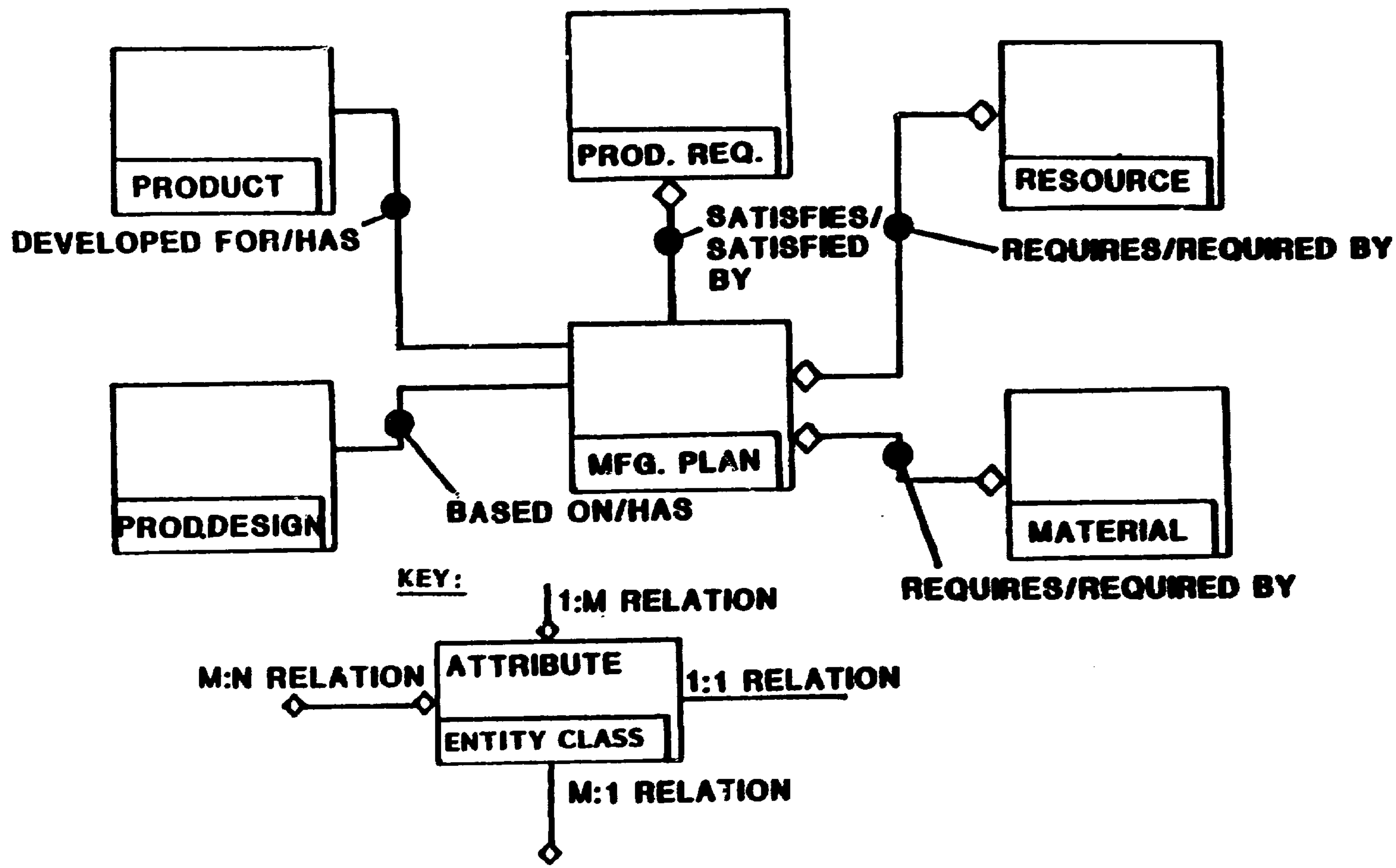
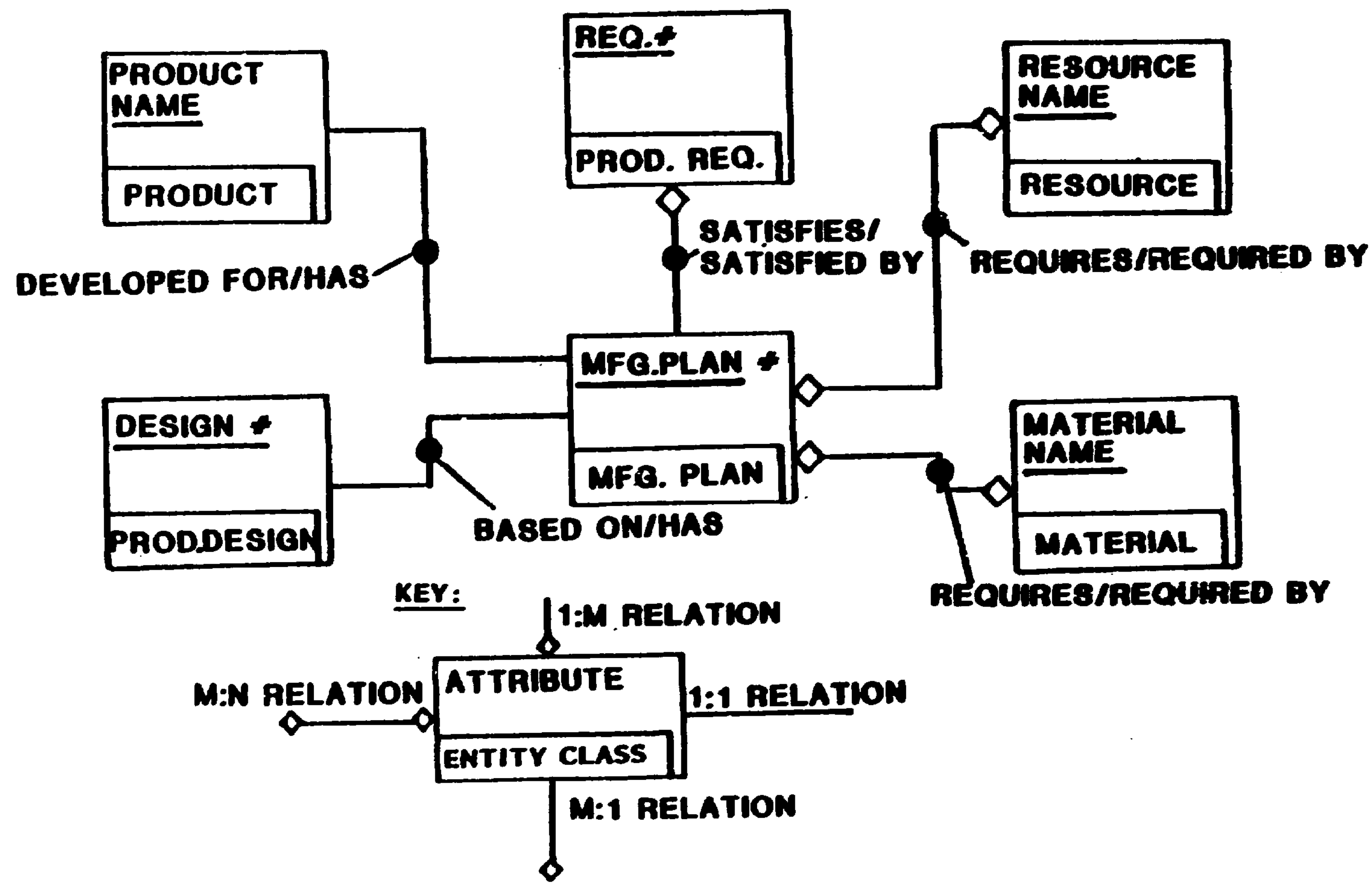


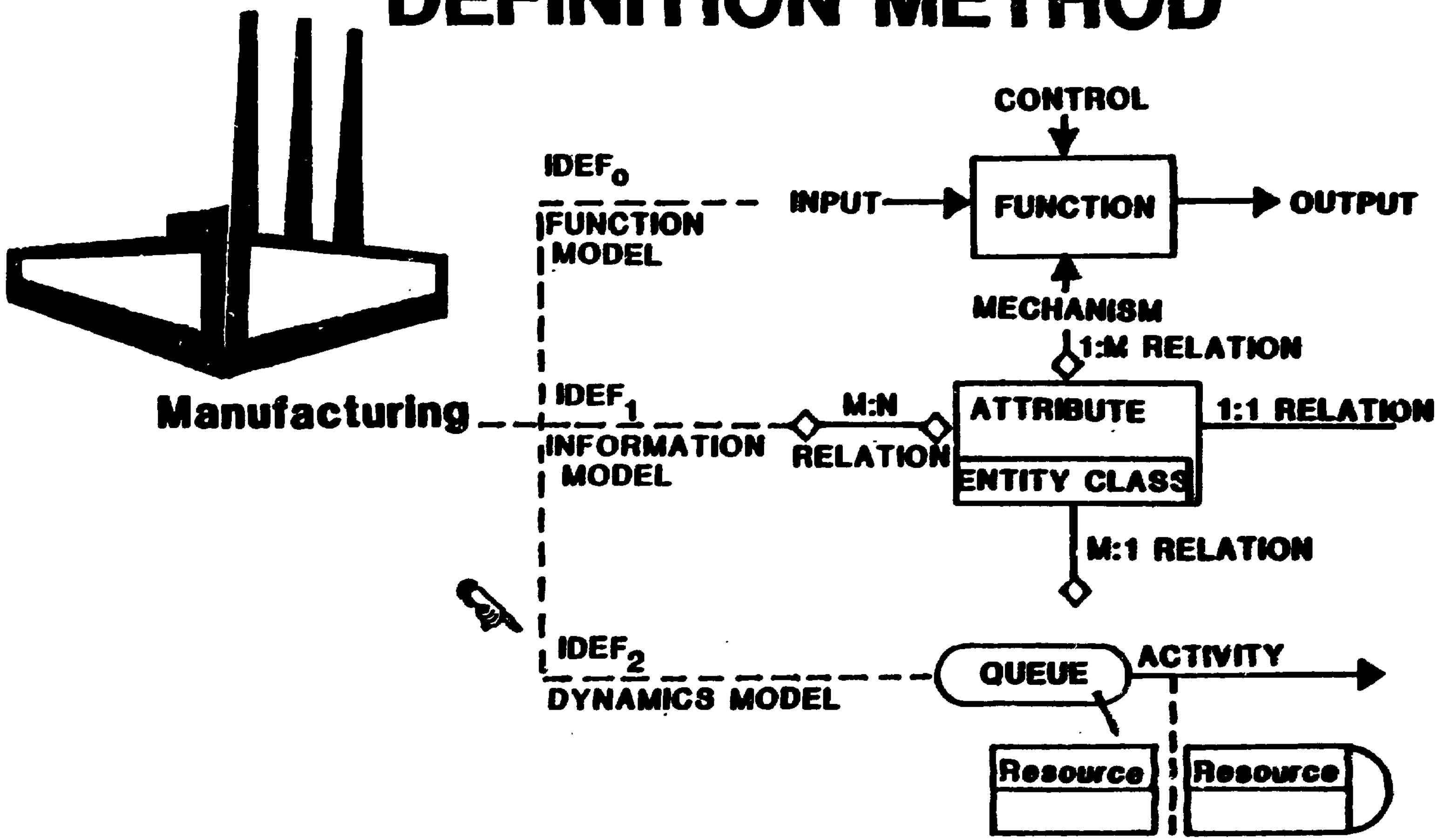
IDEF$_1$ → INFORMATION MODEL



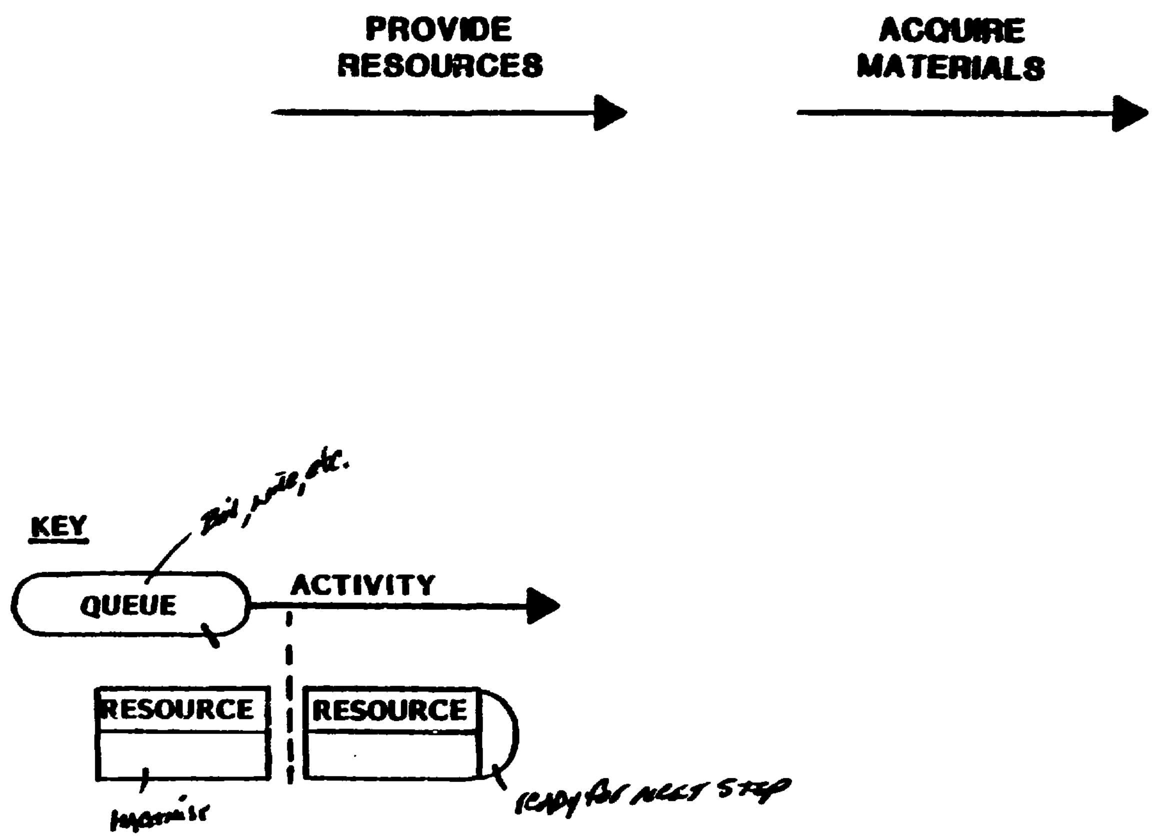
IDEF$_1$ → INFORMATION MODEL



IDEF - A SYSTEM DEFINITION METHOD



IDEF$_2$ → DYNAMICS MODEL



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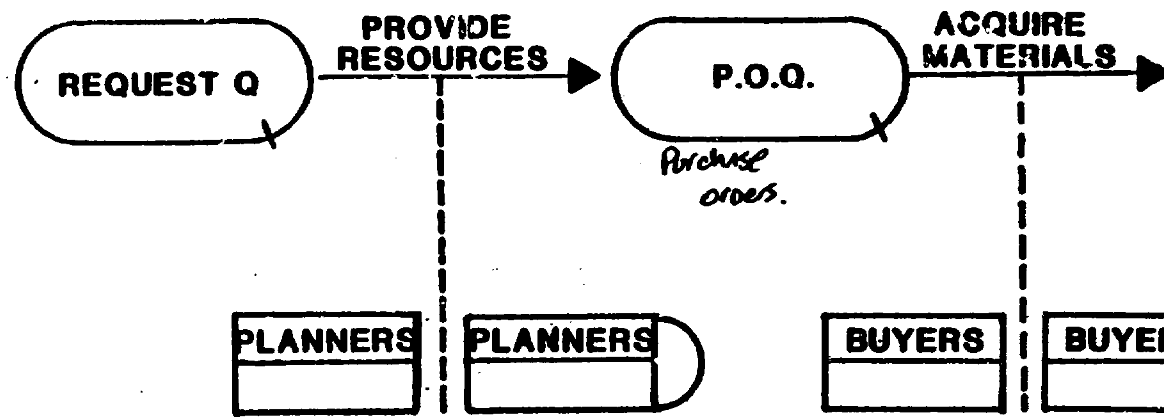

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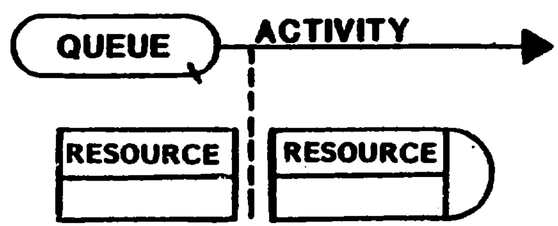

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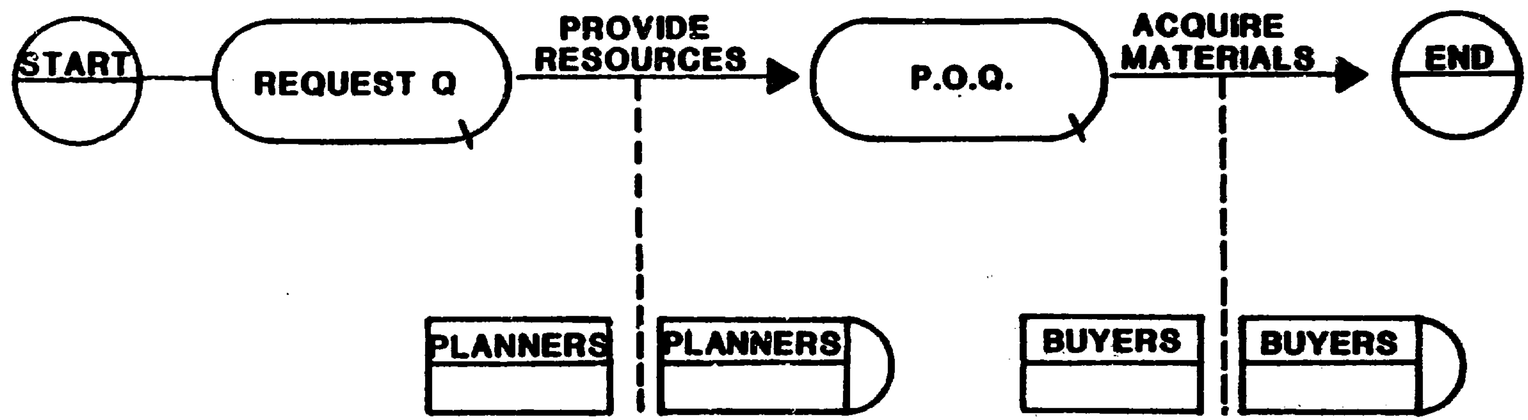

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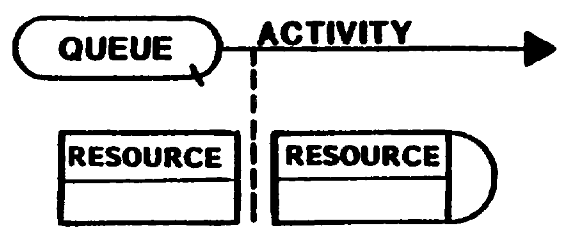
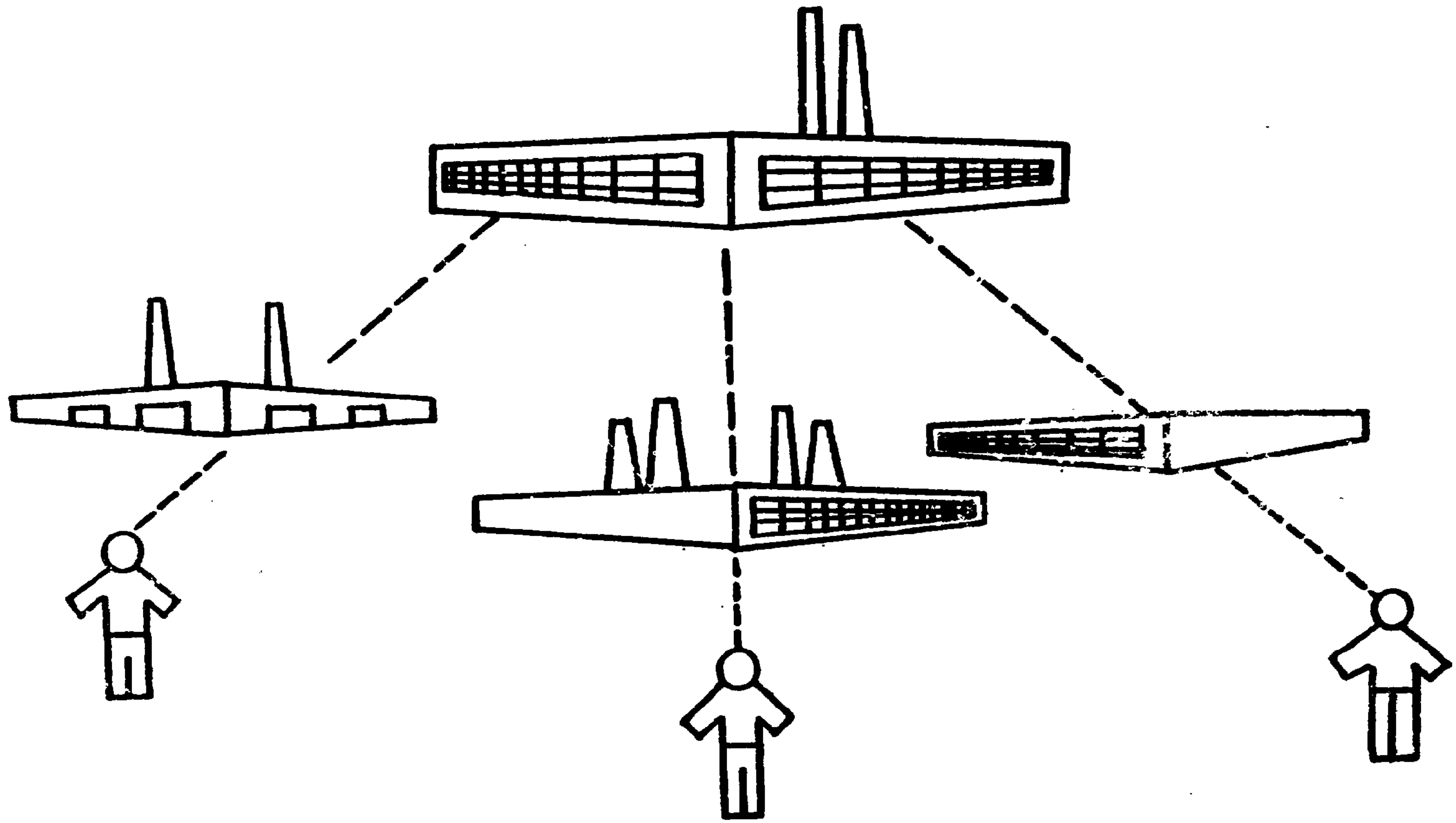


HOW DOES IDEF RELATE TO ARCHITECTURE ?

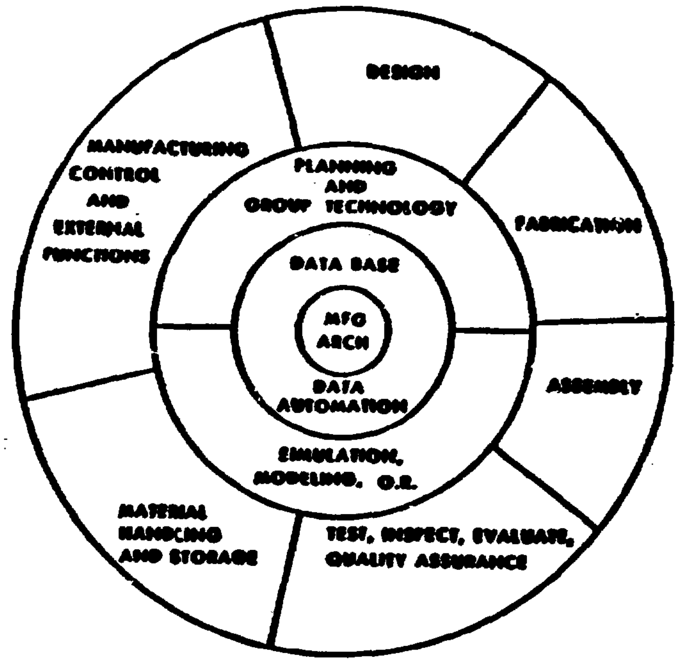
ARCHITECTURE

STANDARD FOR COMMUNICATION

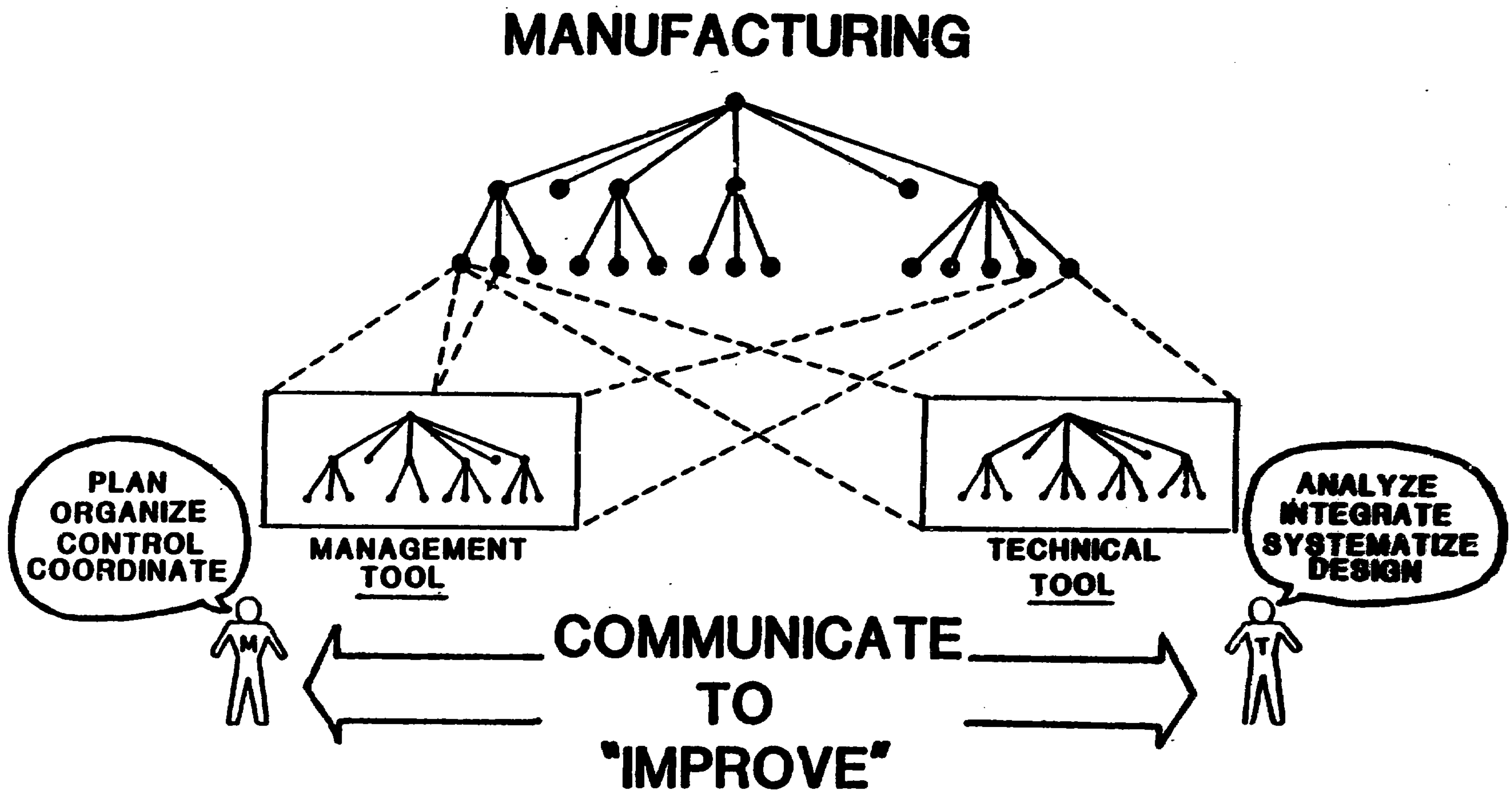


ICAM

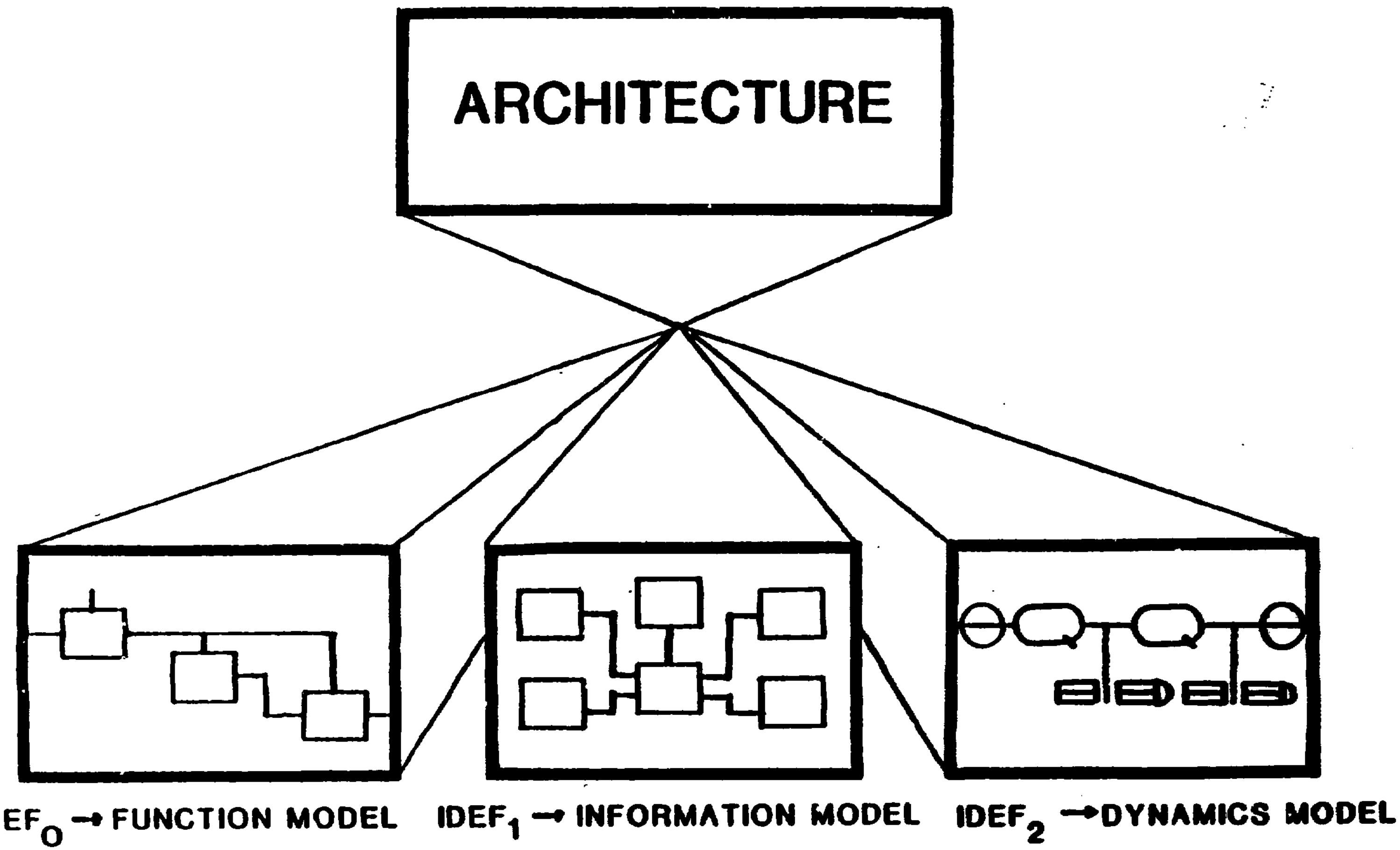
INTEGRATED COMPUTER-AIDED MANUFACTURING



ARCHITECTURE

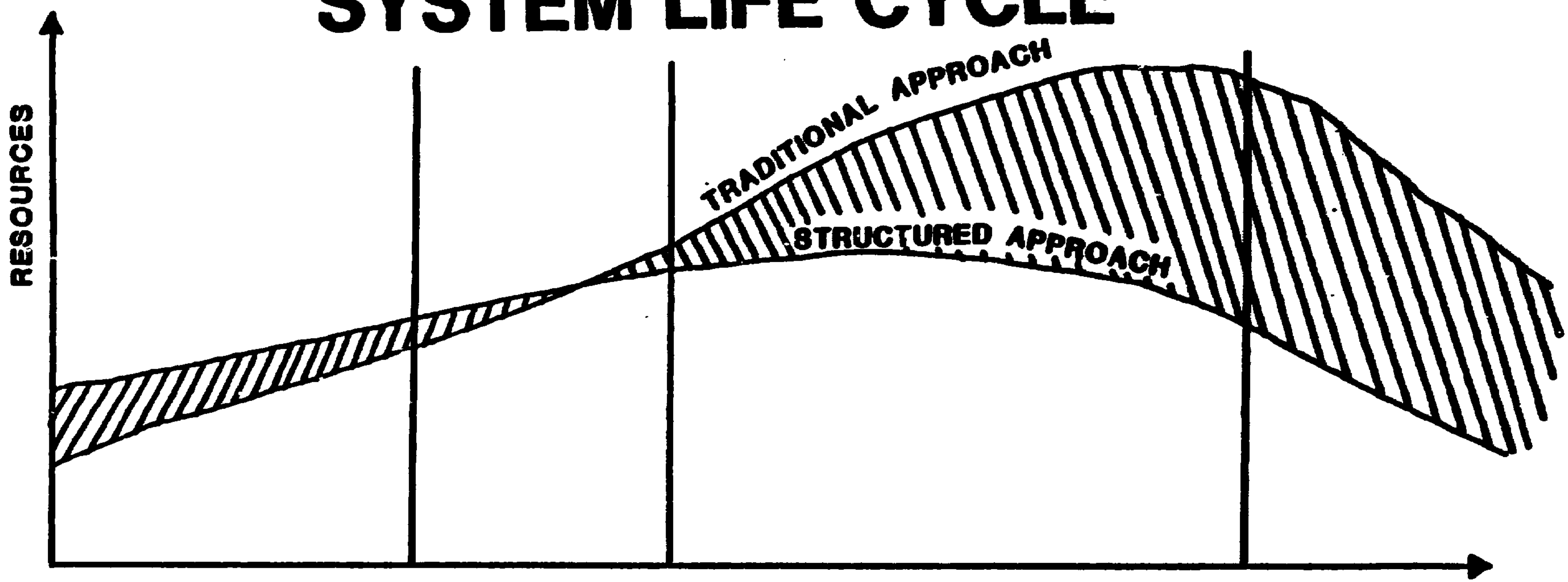


ARCHITECTURE



IDEF ➞ ARCHITECTURE

SYSTEM LIFE CYCLE



UNDERSTANDING PROBLEM	DESIGN	SOLUTION BUILDING	INSTALL & USE
● NEEDS ANALYSIS ● REQUIREMENTS DEFINITION	● PRELIMINARY ● DETAIL SPECIFICATION	● CONSTRUCTION, VERIFICATION, TEST ● INTEGRATION, VALIDATION, TEST	● IMPLEMENTATION ● USER ACCEPTANCE ● MAINTENANCE

ICAM OBJECTIVE

IDEF AND ARCHITECTURE ARE TOOLS ....

NOT OBJECTIVES

IDEF IS THE **METHOD**

ARCHITECTURE IS THE **MEANS**

PRODUCTIVITY IS THE **OBJECTIVE**

SECTION V.

RELIABILITY AND MAINTAINABILITY (R&M) ISSUES IN ROBOT DESIGN

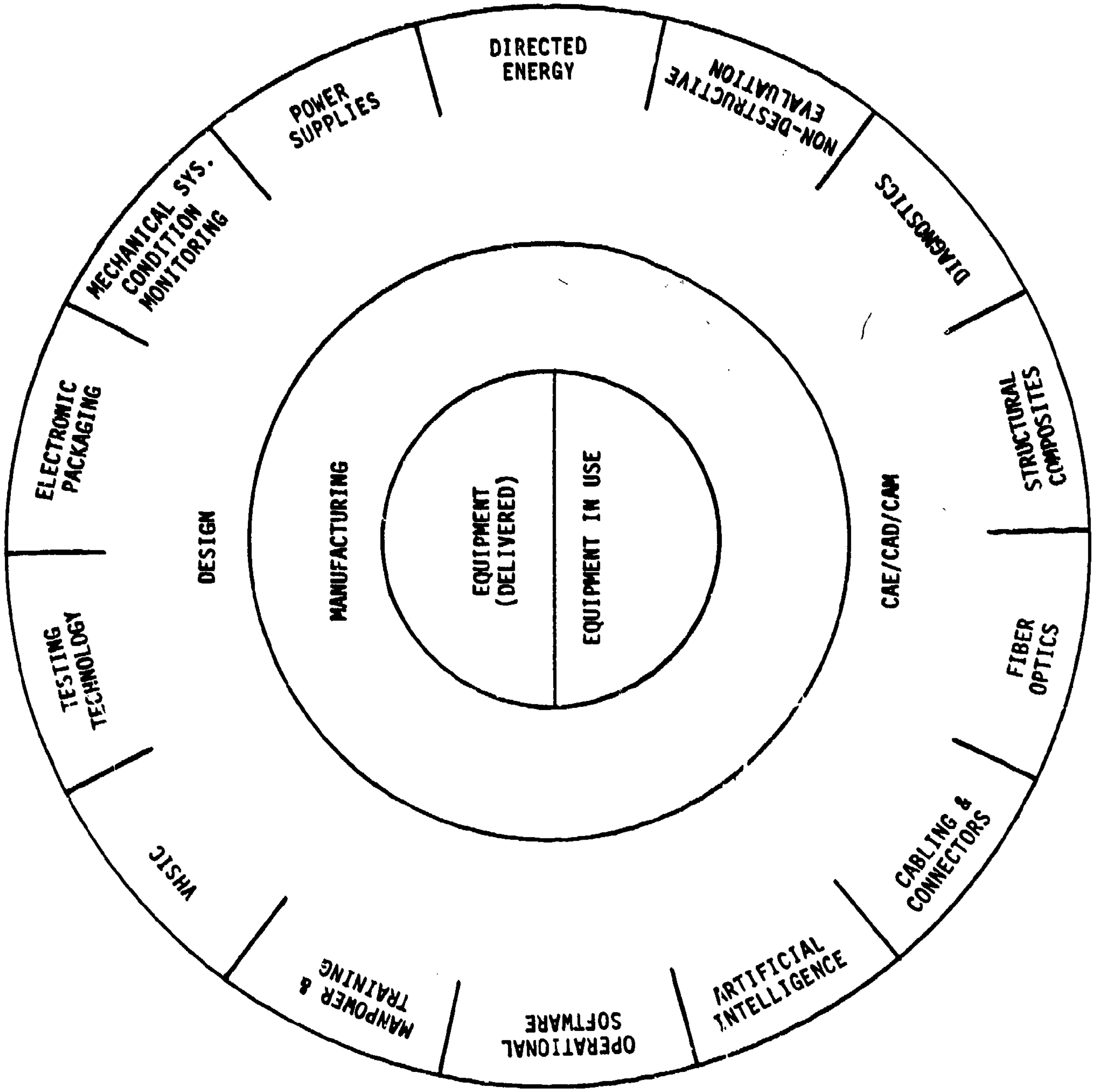
A. RELIABILITY, MAINTENANCE AND SAFETY

Industrial experience indicates that for most applications, uptime must exceed 97 percent to satisfy users of industrial robots. Many applications require an even higher performance.

What we consider the most definitive discussion of robot reliability appears in Joseph Engelberger's book, Robotics in Practice. We feel that this subject deserves very thorough treatment and should be examined separately.

SECTION VI.

FINDINGS AND RECOMMENDATIONS


EQUIPMENT (DELIVERED)
EQUIPMENT IN USE
MANUFACTURING
DESIGN
CAE/CAD/CAM
DIRECTED ENERGY
NON-DESTRUCTIVE EVALUATION
DIAGNOSTICS
STRUCTURAL COMPOSITES
FIBER OPTICS
CABLING & CONNECTORS
ARTIFICIAL INTELLIGENCE
OPERATIONAL SOFTWARE
MANPOWER & TRAINING
VHSIC
TESTING TECHNOLOGY
ELECTRONIC PACKAGING
MECHANICAL SYS. CONDITION MONITORING
POWER SUPPLIES

FINDINGS AND RECOMMENDATIONS

A. DESIGN, MANUFACTURE AND MAINTENANCE

The diagram in Figure 1 provides a useful concept for considering the roles of each of the IDA Technology Steering Group technologies in providing reliability and maintainability (R&M) to DoD equipment and systems. In viewing the outer circle, we should first observe that if R&M is not designed into our systems, they will not be reliable. This, then, underscores the critical role that design plays and should play in ensuring reliable systems.

Design

Our inevitable conclusion must be that design engineers are our first line of attack on the problems of reliability. To do their job effectively, they must (1) possess broad interdisciplinary skills and (2) have the very latest information (continuously updated) as to the role that each of the contributing technologies of our systems have to make to the overall realibility, as well as performance, of those systems.

This requirement suggests (a) a heavy concentration of computer-assisted technologies at the hands of our designers to effect the information access and transfer, as well as (b) training and organization for the designers.

Manufacture

In manufacturing, robotics provides for the effective translation of reliability in design to reliability in the finished product. Management systems are required to monitor and assure this effective implementation once R&M in design is more clearly articulated in design methods. That the translation or implementation be <u>cost</u>-effective as well, may further assure that the cost of reliability is affordable.

Maintenance

On the other hand, robotics and/or automated systems have a great deal to offer the achievement of reliability in existing and future systems in the DoD inventory. The idea of fully automated depots, and perhaps field units, efficiently diagnosing and treating out-of-service

equipment holds a great deal of promise for immediate, albeit incremental, gains in the uptime or availability of equipment.

These immediate gains will be realized through the early introduction of highly computerized man-in-the-loop maintenance systems that will become the forerunners of those same functions performed solely by automated methods as robotic technologies mature.

Procurement

Even more important implications of this committee's findings and recommendations can be seen for procurement policies. Coining a new term, "life-cycle manufacturing," for our purposes, we suggest requiring contractors to deliver not only equipment and manuals and training to fulfill their contracts, but fully automated (as fully as possible) and computer articulated maintenance systems. In effect, we would like our contractors to be as responsible for the life-cycle performance and up-time of their products as they are for the delivered performance. Although DoD initial purchase costs would be increased under such a plan, life-cycle costs should improve considerably, along with operational readiness. We see nothing but good coming from requiring contractors to compete with one another on the life-cycle quality of their systems as well as on delivered performance.

SOURCE OF FINDINGS

The ISOM Committee's work has been influenced heavily by the following sources:

- Intelligent Task Automation Project - Martin-Marietta
- Tour/review of Kelly AFB engine overhaul and repair facilities
- Review of Oklahoma City/Battelle Engine Division study
- Technology Steering Group meetings -- a rich source of interdisciplinary perspective
- Individual members of the ISOM Committee

SUMMARY OF FINDINGS

- The R&M of equipment is principally effected at design time.
- Robotics in manufacture essentially contributes to effective implementation of good design.
- Robotics in maintenance presents us with an opportunity to significantly improve the operational readiness of our existing and future inventories.
- Procurement policies that require computer-articulated man/machine maintenance systems of contractors may make a significant contribution to life-cycle cost savings and to operational readiness.
- Further synthesis of analytical methodologies and further demonstration of flexible robotic technology will contribute significantly to advances in operational readiness.

SUMMARY OF RECOMMENDATIONS

A. TECHNOLOGY DEVELOPMENT

1. Integrated Manufacturing Systems analysis methodologies reviewed, further synthesized and applied to engine overhaul and repair at Kelly AFB to produce management guidelines for ISOM decision-making.

2. Design and pilot of a training program for applying ISOM analysis and methodologies.

3. Design and pilot of a CAE/CAD system designed to optimize technology information input to the design process--for a particular product currently under development (and/or one recently developed).

B. TECHNOLOGY DEMONSTRATION

1. Develop and pilot test an automated repair facility for the Blackhawk (UH-68) Intermediate Gear Box (IGB).

2. Major man-in-the-loop automated implementation at Kelly AFB for engine overhaul and repair, to proceed from the ISOM analysis methodology pilot at Kelly described above.

3. Targeted Life-Cycle manufacturing procurement exercise for a product currently under development.

SUMMARY OF RECOMMENDATIONS
($Thousands)

A1	Robotic Analysis Methodology	$ 1,500
A2	Methodology Pilot and Training	2,500
A3	Technology in Design Pilot	5,000
B1	Blackhawk IGB Repair Facility	3,000
B2	Engine Overhaul Methodology Pilot	12,000
B3	Procurement Pilot	1,500
	TOTAL	$25,500

Figure 2

APPENDIX A:

ISOM CORE GROUP PRESENTATION

INTEGRATED SYSTEMS OF MANUFACTURING

(ROBOTICS)

CORE GROUP PRESENTATION

MAY 11, 1983

ISOM COMMITTEE MEMBERS

MR. DANIEL S. APPLETON	D. APPLETON COMPANY, INC.
MR. JOSEPH H. BOSWORTH	RB ROBOT CORPORATION
MR. BRUCE W. CHRIST	NATIONAL BUREAU OF STANDARDS
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MR. JOHN MEYER	TECH TRAN
MR. ROGER SCHAPPELL	MARTIN MARIETTA AEROSPACE
MR. JOHN M. SHERICK	MOUNTAIN STATES ENERGY

5-11-83

ISOM AGENDA

I. RELIABILITY, MAINTAINABILITY AND NEW TECHNOLOGY: A METHODOLOGY

II. ROBOTICS AND R & M

III. SMALL LOT MANUFACTURING

IV. RECOMMENDATIONS

5-11-83

I. RELIABILITY, MAINTAINABILITY AND NEW TECHNOLOGY: A METHODOLOGY FOR ANALYSIS AND IMPLEMENTATION

A. HOW DO WE "BUILD-IN" RELIABILITY AND MAINTAINABILITY

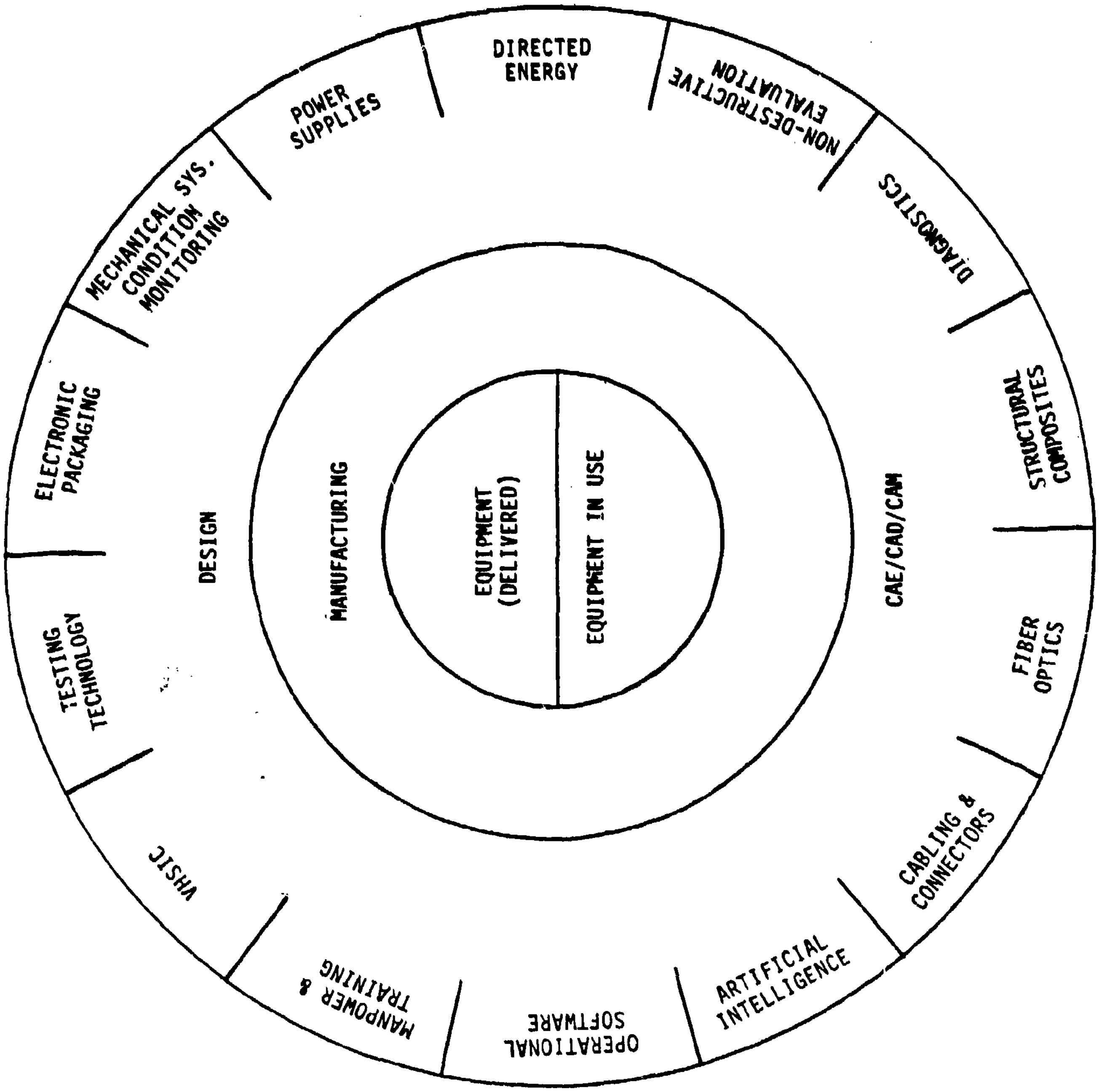
- DESIGN

B. HOW DO WE COORDINATE AND EFFECTIVELY IMPLEMENT FEATURES OF THE NEW TECHNOLOGIES

- WE MUST HAVE THE NEW TECHNOLOGIES IN APPROPRIATE PERSPECTIVE AND CONTEXT
- WE MUST TRAIN (AND CONTINUOUSLY UPDATE THE TRAINING OF) DESIGN ENGINEERS
- WE MUST PROVIDE THE DATA IN SUPPORT OF DESIGN

5-11-83

5-11-83



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NON-DESTRUCTIVE EVALUATION
DIAGNOSTICS
STRUCTURAL COMPOSITES
FIBER OPTICS
CABLING & CONNECTORS
ARTIFICIAL INTELLIGENCE
OPERATIONAL SOFTWARE
MANPOWER & TRAINING
VHSIC
TESTING TECHNOLOGY
ELECTRONIC PACKAGING
MECHANICAL SYS. CONDITION MONITORING
POWER SUPPLIES
DESIGN
MANUFACTURING
CAE/CAD/CAM
EQUIPMENT (DELIVERED)
EQUIPMENT IN USE

II. ROBOTICS AND R & M

A. ROBOTICS IN MANUFACTURING

B. ROBOTICS IN MAINTENANCE

C. LIFE CYCLE MANUFACTURING

5-11-83

A. ROBOTICS IN MANUFACTURING (RE: RELIABILITY AND MAINTAINABILITY)

1. RESPONSIVENESS TO DESIGN - PARTICULARLY AS DESIGN PROCESS BECOMES MORE CRITICAL AND PUTS MORE DEMANDS ON MANUFACTURING

2. QUALITY/PRECISION OF WORKMANSHIP

3. TIMING (SMALL LOT MANUFACTURING)

4. COST - MONEY TO PLOW BACK INTO R & M

5-11-83

B. ROBOTICS IN R & M

- INSPECTION ROBOTS
- FIX-IT ROBOTS

---

1. REDUCE DOWNTIME
2. REDUCE MANPOWER REQUIREMENT
   - NUMBERS
   - SCOPE OF TRAINING

5-11-83

ROBOTICS IN R & M: CASE STUDIES

1. MAJOR ENERGY COMPANY: SPOT WELDS - REJECT RATES

    - 60% REJECT OF WELDS - BY MAN IN FIELD (PIPELINERS) - REQUIRING EXPENSIVE REWORK
    - 2% REJECT OF WELDS - OFFSHORE BY AUTOMATIC EQUIPMENT

2. INTELLIGENT WORK CELL: F111 TAIL ASSEMBLY (COMPOSITES)

    - REAL TIME - ROBOT INSPECTION AND OPERATION
    - INFORMATION MANAGEMENT
    - SUPERVISORY SYSTEM

3. INTELLIGENT TASK AUTOMATION: F15 BULKHEAD

    - VISION
    - 3D LASER SCANNER
    - ADAPTIVE CONTROLS
    - APPLIED AI
    - TARGET: 8 HOURS INSTEAD OF 200 HOURS

5-11-83

ROBOTICS IN R & M: TWO STAGES

1. MAN IN LOOP

2. MAN NOT IN LOOP

5-11-83

C. LIFE CYCLE MANUFACTURING

- PRECEDENT: WARRANTIES

---

1. DESIGN NOT ONLY FOR AUTOMATED MANUFACTURE, BUT FOR AUTOMATED MAINTENANCE

2. PROCURE PRODUCTS FOR THEIR USEFUL LIFE

   CURRENT: EQUIPMENT DELIVERED: MAN, TRAINING AND MANUAL TAKE OVER - INEFFECTIVE ACCOUNTABILITY LINK TO ORIGINAL MANUFACTURER

   PROPOSED: EQUIPMENT DELIVERED WITH MAINTENANCE WORK CELLS AND SYSTEMS - STRONG ACCOUNTABILITY ESTABLISHED FOR MANUFACTURER'S DESIGN WORK AND PERFORMANCE

3. MANUFACTURERS WILL COMPETE ON BASIS OF R & M OF THEIR PRODUCTS

5-11-83

III. SMALL LOT MANUFACTURE

- ICAM
- IDEF
- IMTP

---

1. ECONOMICS
2. MOBILIZATION READINESS
3. R & M

5-11-83

IV. RECOMMENDATIONS

A. TECHNOLOGY STEERING GROUP REPORT - INCORPORATE ACTION CONTEXT FOR WHOLE OF STEERING GROUP'S TECHNOLOGIES

- FOCUSING ON THE MANUFACTURE AND LIFETIME SUPPORT OF EQUIPMENT
- FOCUSING ON PROCUREMENT POLICIES
- EMPHASIS IN DESIGN PHASE FOCUS AND SUPPORT

B. SEVERAL SERIOUS DOWNTIME PROBLEMS BE ANALYSED AND FUNDED FOR TOTAL R & M TREATMENT (TARGET - QUANTUM IMPROVEMENTS)

A TYPICAL R & M "TREATMENT" EFFORT

- TRAINED ROBOTICS ANALYSTS
- EXPERTS ON THE EQUIPMENT UNDER "TREATMENT"
- COMPUTER
- PROGRAMMERS
- SOFTWARE (IDEF AND OTHERS)
- MAINTENANCE ENGINEERS
- DATABASE ON THE EQUIPMENT
  - DESIGN
  - MAINTENANCE

5-11-83

APPENDIX B:

ROBOT VEHICLES

052

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TECHNICAL REPORT SUMMARIES

SEARCH CONTROL NO. 021533

ROBOTIC VEHICLES (U)

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FIRST LEVEL SEARCH TERMS

- AIR CUSHION VEHICLES
- AIRCRAFT TRACTORS
- AMBULANCES
- AMPHIBIOUS VEHICLES
- ARMORED PERSONNEL CARRIERS
- ARMORED VEHICLES
- AUTOMOTIVE VEHICLES
- BOMB HANDLING VEHICLES
- BOMB TRUCKS
- BOXCARS
- BULLDOZERS
- CAPTIVE AIRSPACE CRAFT
- CARGO VEHICLES
- COMBAT VEHICLES
- CRASH VEHICLES
- DEEP SUBMERGENCE RESCUE VEHICLES
- DEEP SUBMERGENCE VEHICLES
- DUMP TRUCKS
- ELECTRIC AUTOMOBILES
- FIRE FIGHTING VEHICLES
- FORKLIFT VEHICLES
- FUEL TRUCKS
- GONDOLAS
- GROUND EFFECT MACHINES
- GROUND VEHICLES
- LOCOMOTIVES
- LUNAR SURFACE VEHICLES
- MAINTENANCE VEHICLES
- MILITARY VEHICLES
- MOTORCYCLES
- PASSENGER VEHICLES
- RAILROAD CARS
- RECOVERY VEHICLES
- RESCUE VEHICLES
- ROCKET SLEDS
- SCOUT CARS
- SELF PROPELLED GUNS
- SEMITRAILERS
- SLEDS
- SNOW VEHICLES
- SURFACE EFFECT VEHICLES

SEARCH STRATEGY FOR ***021533*** (CONTINUED)

SWIMMER VEHICLES
TANK CARS
TANKS(COMBAT VEHICLES)
TOWED VEHICLES
TOWING VEHICLES
TRACKED VEHICLES
TRACTORS
TRAILERS
TRUCKS
UNDERWATER VEHICLES
UTILITY VEHICLES
VANS
VEHICLES
WEAPONS CARRIERS

SECOND LEVEL SEARCH TERMS

ARTIFICIAL INTELLIGEN	(TRUNCATED)
COMPUTER AIDED	(TRUNCATED)
COMPUTER ASSISTED	(TRUNCATED)
COMPUTER BASE	(TRUNCATED)
REMOTE CONTROL	(TRUNCATED)
ROBOT	(TRUNCATED)

THIRD LEVEL SEARCH TERMS

ACOUSTIC MINESWEEPING	
AERIAL MINE WARFARE	
CMU(COUNTERMINE	(TRUNCATED)
COUNTERMINE VEHICLE	(TRUNCATED)
DECISIONMAKING	
LAND MINE WARFARE	
MAGNETIC MINESWEEPING	
MINE	(TRUNCATED)
MINE CLEARANCE	
MINE COUNTERMEASURES	
MINE DETECTION	
MINE HUNTING	
MINE NEUTRALIZATION	
MINE WARFARE	
MINEFIELDS	
MINELAYING	
MINELAYING EQUIPMENT	
MINESWEEPING	
NAVAL MINE WARFARE	
TERRAIN	(TRUNCATED)

DTIC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. 021533

AD-A122 001 19/1 13/6

STANDARD MFG CO INC DALLAS TEX

Remote Controlled Vehicle Mounted Minefield Detector System. (U)

DESCRIPTIVE NOTE: Final rept. Feb-Aug 82,
NOV 82 123P Hudler,Dennis W. ;Taylor, Kermit D. ;
REPT. NO. R6929-4
CONTRACT: DAAK70-82-C-0052

UNCLASSIFIED REPORT

ABSTRACT: The purpose of this study was to determine the feasibility and optimum design concept for a remotely controlled ground vehicle to locate mines and minefields. Evaluation was to be based on current technology, equipment and mission considerations, and threat assessment. The envisioned vehicle utilization indicated the need for a lightweight, highly maneuverable vehicle equipped with radio controls, television monitor, minefield marking device, and a very good detection system. These features are necessary to insure system survival, reliable operation, and provide standoff distance for operator safety. Addition of other equipment is also envisioned for use on special purpose missions, thereby increasing system utility and value. All these pieces of equipment exist and can be operated using a remote control system. Vehicle mobility, maintainability, and cost factors indicate that the optimum vehicle configuration be a 6-wheeled all terrain unit utilizing hydrostatic drive and skid steering. Vehicle will be powered by a diesel engine for maintenance, efficiency, and logistical interface with current Army units. These systems are also readily adapted to remote control applications. (Author) (U)

DESCRIPTORS: *Mine detection, *Mine clearance, *Ground vehicles, *Remote control, Utility vehicles, Materials handling vehicles, Lightweight, Maneuverability, Feasibility studies, Optimization, Mission profiles, Utilization (U)

IDENTIFIERS: Radio control (U)

DTIC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. 021533

AD-A118 474 6/4 9/2 13/6

OHIO STATE UNIV RESEARCH FOUNDATION COLUMBUS

An Experimental Study of an Ultra-Mobile Vehicle for Off-Road Transportation. (U)

DESCRIPTIVE NOTE: Semi-annual technical rept. 1 Oct 81-31 Mar 82,
AUG 82 92P McGhee,Robert B. ;Waldron, Kenneth J. ;
CONTRACT: MDA903-82-K-0058

UNCLASSIFIED REPORT

ABSTRACT: This report summarizes research accomplished during the first six months of a project aimed at field testing of an experimental vehicle making use of an actively controlled suspension system for improved off-road mobility. The first year of this project involves component evaluation and concept verification with reduced-scale laboratory models. Preliminary test results and projections of performance to be expected in the full-scale vehicle are included in this report. (Author) (U)

DESCRIPTORS: *Automata, *Control systems, Vehicles, Offroad traffic, Computer programs, Servomechanisms, Hydraulic actuators, Suspension devices, Legs, Frames, Chassis, Computers, Telescoping structures, Locomotion, Terrain, Roughness, Mechanical energy, Storage, Advanced weapons, Walking, Lasers (U)

IDENTIFIERS: Walking machines, *Robotics, *Robots, Legged locomotion, Laser systems, LPN-OSURF-762945/714250 (U)

AD-A097 889 19/3 9/2

STEVENS INST OF TECH HOBOKEN NJ DAVIDSON LAB

An Output Diagnosis Program for the NATO Reference Mobility Model. (U)

DESCRIPTIVE NOTE: Final rept.,
DEC 80 33P Brady,Peter M. , Jr;
REPT. NO. SIT-DL-80-9-2183
CONTRACT: DAAK30-80-C-0032

UNCLASSIFIED REPORT

ABSTRACT: The NATO Reference Mobility Model (NRMM) produces a prediction of the speed at which a vehicle can traverse an area (terrain unit). The program described here uses selected values calculated in the NRMM to determine the factor which is the limiter for a vehicle and terrain unit. In the case of a NO-GO prediction, the reason for the NO-GO is deduced. Detailed and summary diagnostic tables are produced together with a graphical presentation of the diagnostics. (Author) (U)

DESCRIPTORS: *Computer aided diagnosis, *Mobility, Combat vehicles, Terrain following, Ground speed, Offroad traffic, Output, Input output processing, Computer programming (U)

AD-A091 428 19/3 9/2 5/9

SINGER CO BINGHAMTON NY LINK DIV

Design Definition Study Report. Full Crew Interaction Simulator-Laboratory Model (FCIS-LM) (Device X1787). Volume VII. Conclusions. (U)

DESCRIPTIVE NOTE: Final rept.
MAY 78 22P
REPT. NO. LR-895-VOL-7
CONTRACT: N61339-77-C-0185
MONITOR: NAVTRAEQUIPC 77-C-0185-0001-7

UNCLASSIFIED REPORT

SUPPLEMENTARY NOTE: See also Volume 1, AD-A091 422.

ABSTRACT: This Design Definition Study Report is the preliminary phase of a three-part task performed by the Link Division of the Singer Company to determine the technical feasibility and optimum design for a Full Crew Interactive Simulator-Laboratory Model (FCIS-LM) for the M60A3 main battle tank. The report documents the investigative and analytical efforts conducted to establish training objectives and requirements for the FCIS-LM device, and the development of critical simulation area design approaches to meet those training requirements. Subsequent phases 2 and 3, the FCIS-LM Performance Specification and FCIS-LM Technical Proposal respectively, utilize the findings and design concepts provided in the study report to establish the final design and proposed approach to providing a complete FCIS-LM device. (U)

DESCRIPTORS: *Tanks(Combat vehicles), *Computer aided design, *Army training, Simulators, Integrated systems, Degrees of freedom, Visual targets, Terrain, Mobility, Training devices, Fire control computers, Feasibility studies, Military requirements, Cost effectiveness, Computerized simulation, Reliability, Maintainability (U)

IDENTIFIERS: *M-60A3 tanks, Main battle tanks, X-1787 training devices (U)

AD-A091 425 19/3 9/2

SINGER CO BINGHAMTON NY LINK DIV

Design Definition Study Report. Full Crew Interaction Simulator-Laboratory Model (FCIS-LM) (Device X17B7). Volume IV. Motion. (U)

DESCRIPTIVE NOTE: Final rept.
JUN 78 62P
REPT. NO. LR-895-VOL-4
CONTRACT: N61339-77-C-0185
MONITOR: NAVTRAEQUIPC 77-C-0185-0001-4

UNCLASSIFIED REPORT

SUPPLEMENTARY NOTE: See also Volume 5, AD-A091 426.
ABSTRACT: For abstract see AD-A091 422. (U)
DESCRIPTORS: *Tanks(Combat vehicles), *Computer aided design, *Army training, Simulators, Mobility, Combat effectiveness, Equations of motion, Degrees of freedom, Motion, Trade off analyses, Tank crews, Military requirements, Terrain, Computerized simulation (U)
IDENTIFIERS: *M-60A3 tanks, Main battle tanks, X-17B7 training devices (U)

AD-A072 532 5/9 15/7

HUMAN RESOURCES RESEARCH ORGANIZATION ALEXANDRIA VA

User Manual for the Miniature Armor *Battlefield (MAB)*. Appendix C. *Criterion* Tests. Appendix D. How to Construct Terrain Features. Appendix E. Details of Radio Control Equipment. Appendix F. Housing and Training Platform for the MAB. (U)

82 154P
CONTRACT: DA-44-188-ARO-2

UNCLASSIFIED REPORT

SUPPLEMENTARY NOTE: Appendix C thru F to report dated Mar 82 (Revised), AD-A072 530. See also Appendix A and B, AD-A072 531.

DESCRIPTORS: *Training devices, *Terrain models, *Battlefields, Tank crews, Military exercises, Simulation, Tanks(Combat vehicles), Models, Remote control, Radio equipment, Land combat, Decision making, Military tactics (U)
IDENTIFIERS: *MAB(Miniature Armor Battlefield) (U)

AD-A065 158 6/5

DEFENCE AND CIVIL INST OF ENVIRONMENTAL MEDICINE DOWNSVIEW (ONTARIO)

Canadian Diving Symposium (3rd) Held at Defence and Civil Institute of Environmental Medicine, 30 - 31 October 1978. (U)

OCT 78 122P

UNCLASSIFIED REPORT

ABSTRACT: Contents: Uses and Development in Remotely Controlled Underwater Vehicles in Canada; Development of a Hyperbaric Blower; Operation MANTIS, DDF First Pressurization; DCIEM Deep Diving Program; Regulations Respecting Diving Operations in Support of Offshore Mineral Resource Activity; Atlantic Marine Diving Operations Past, Present and Future (Audio-visual presentation); Dive Monitoring and Equipment - Supervision and Recording; Industry, Trade and Commerce and Underwater Canada; Innovation in Underwater Illumination - The Ballastless Gas Discharge Light; CC'STRUCTOR Diving System (Audio-visual presentation); Excavation of the Sapphire - A 1696 British Frigate; Man Underwater, Medicine and Miracles; Diving Operations in Support of Arctic Offshore Explorations; Search for an Arctic Shipwreck; Armed for Deep Water (Audio-visual presentation). (U)

DESCRIPTORS: *Diving, *Symposia, Canada, Underwater vehicles, Remote control, Minerals, Offshore, Monitoring, Recording systems, Sapphire, Deep water (U)

IDENTIFIERS: MANTIS Operation (U)

AD-A059 770 15/7 19/1 19/3

NAVAL WAR COLL NEWPORT RI CENTER FOR ADVANCED RESEARCH

A Dynamic Analysis of the Medium Tank Battalion Conducting Hasty Offensive Operations. (U)

DESCRIPTIVE NOTE: Final rept.,
JUN 78 343P Schurtz,Gerald P. ; McConville,Frederick J. ;Lowe,Henry J. ; Steele,James J. ;

UNCLASSIFIED REPORT

Availability: Document partially illegible.

ABSTRACT: An analysis of alternate offensive tactics was conducted using the computer-assisted manual war game BATTLE (Battalion Analyzer and Tactical Trainer for Local Engagements). The purpose of the study was to determine which of two sets of tactical procedures is better for the conduct of a hasty attack against a reinforced Soviet motorized rifle battalion defending dominant terrain. Variations in attack formations, composition and size of the overwatch force, characteristics of avenues of approach, the use of scouts, and the employment of smoke munition under varying weather conditions were examined. The scope of the study was bounded by specific conditions regarding terrain, visibility, weather, enemy dispositions, and friendly force organizations. Two U.S. tank battalion organizations, each with 54 tanks, an organic TOW company, a mechanized infantry company and supported by indirect fire units, conducted the attacks. Close air support and attack helicopters were excluded. Tactics which create a partial or complete envelope of smoke around the attacking force concentrated on a mass formation consistently achieved the objective at least cost in terms of U.S. weapons systems destroyed. Areas for further research are identified. (Author) (U)

DESCRIPTORS: *War games, *Tactical analyses, *Tanks(Combat vehicles), Attack, Battalion level organizations, Company level organizations, Terrain models, Central Europe, Field army, Tactical warfare, Artillery fire, Smoke munitions, Camouflage, Weather, Computer aided diagnosis (U)

AD- 861 954 19/1 13/6

ARMY CONCEPT TEAM IN VIETNAM APO SAN FRANCISCO 96384

Evaluation of Remotely Operated Mine Detector. (U)

DESCRIPTIVE NOTE: Final letter rept.,
OCT 69 10P Isbell,Richard A. ;
PROJ: ACTIV-ACG-32/67I, ACTIV-ACG-32/711

UNCLASSIFIED REPORT

ABSTRACT: The Army Concept Team in Vietnam evaluated the Remotely Operated Mine Detector to determine the effectiveness, suitability and, if appropriate, a basis of issue. The evaluation started on 12 May 1969 and continued through 21 July 1969. The four Remotely Operated Mine Detectors were used on mine sweeping operations of main supply routes. (Author) (U)

DESCRIPTORS: (*PASSENGER VEHICLES, MINE DETECTORS), (*MINE DETECTORS, *REMOTE CONTROL), LIMITED WAR, RADIO EQUIPMENT, LAND MINES, TRANSMITTER RECEIVERS, MAINTAINABILITY, PERFORMANCE(ENGINEERING), RELIABILITY(ELECTRONICS), VIETNAM (U)

IDENTIFIERS: EVALUATION, *JEEP MOUNTED MINE DETECTORS, M-151 VEHICLES(1/4-TON), SOUTH VIETNAM (U)

UNCLASSIFIED

DTIC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. 021533

AD- 857 163 13/6 20/11

ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS

Dynamics of Wheeled Vehicles. Report I. A Mathematical Model for the Traversal of Rigid Obstacles by a Pneumatic Tire. Appendix B: Digital Implementation of Segmented Tire Model. (U)

DESCRIPTIVE NOTE: Final rept.,
AUG 69 26P Murphy,Newell R. , Jr;
REPT. NO. AEWES-TR-M-68-1-1-App-B
PROJ: DA-1-T-062103-A-046
TASK: 1-T-062103-A-04603

UNCLASSIFIED REPORT

SUPPLEMENTARY NOTE: Appendix to report dated May 68, AD-834 324.

ABSTRACT: This appendix presents the procedures for digital implementation of the segmented tire model, developed in the basic report for an analog computer. Two procedures are required: (a) determination of the segment spring coefficient from measured load-deflection test results, and (b) computation of the resultant force vector transmitted to the axle. Digital programs for both procedures were written in Fortran IV for a GE-420 system, and are included. (Author) (U)

DESCRIPTORS: (*VEHICLES, TERRAIN), (*TIRES, DYNAMICS), VEHICLE WHEELS, COMPUTER PROGRAMS, MATHEMATICAL MODELS, DIGITAL SYSTEMS, LOADS(FORCES), DEFLECTION, FORCE(MECHANICS), AXLE SHAFTS, DAMPING (U)

IDENTIFIERS: BARRIERS, COMPUTER AIDED ANALYSIS, RESILIENCE, SEGMENTED TIRES (U)

AD- 817 189 6/4 13/6

STANFORD RESEARCH INST MENLO PARK CALIF

APPLICATION OF INTELLIGENT AUTOMATA TO RECONNAISSANCE. (U)

DESCRIPTIVE NOTE: Interim rept. Mar-Nov 66,
MAY 67 196P Green,M. ;Wahlstrom,S. ;
Forsen,G. ;
CONTRACT: AF 30(602)-4147
PROJ: AF-4594, SRI-5953
TASK: 459405
MONITOR: RADC TR-66-822

UNCLASSIFIED REPORT

ABSTRACT: This report describes the results of research during the first eight months on the project Application of Intelligent Automata to Reconnaissance. The primary goal of this project is to investigate techniques in artificial intelligence applied to the control of a mobile automation in a realistic environment. The main emphasis is in the design of a hierarchy of computer programs that will accept visual and other sensory information from the automation and direct its actions toward the completion of missions requiring the abilities to plan ahead and to learn from previous experience. The automation itself is a four-wheeled, self-powered vehicle with two simple arms for grasping objects. It will carry a television camera, an optical range-measuring device, tactile sensors, a transceiver, and storage and routing logic. The vehicle will be radio-controlled by an SDS 940 time-shared computer. The computer, with the aid of special image-processing hardware, will analyze television pictures transmitted from the vehicle and will calculate a sequence of vehicle actions designed to accomplish the task(s) given to the automation. Calculation of the appropriate action sequence will be performed by problem-solving computer programs which will use internally-stored models of the world generated and abstracted during the course of automation explorations. (U)

DESCRIPTORS: (*ARTIFICIAL INTELLIGENCE, *VEHICLES), (*COMPUTERS, *COMPUTER PROGRAMS), NAVIGATION, MOBILITY, PATTERN RECOGNITION, VIDEO SIGNALS, VIDICONS, DISPLAY SYSTEMS, TRAFFICABILITY, TERRAIN AVOIDANCE, TERRAIN, (U)

IDENTIFIERS: ALGOL PROGRAMMING LANGUAGE, SDS 940 (U)

AD- 817 189

UNCLASSIFIED

DTIC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. 021533

AD- 785 627 19/3

ARMY TANK-AUTOMOTIVE COMMAND WARREN MICH

A Technique for the Validation of Vehicle Models using the Road Simulator, (U)

73 14P Grant,James W. ;

UNCLASSIFIED REPORT

ABSTRACT: The report discusses the process from the vehicle concept to prototype field testing in first formulating a mathematical model using the dynamic equations of motion for the suspension system and relevant components of a vehicle concept; then subjecting the model to the mission profile for which the vehicle is intended. (U)

DESCRIPTORS: *Tanks(Combat vehicles), Mobility, *Mathematical models, Terrain, Waterproofing, Models, Simulation (U)

IDENTIFIERS: *Surface mobility, Computer aided design (U)

AD- 785 627

DTIC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. 021533

AD- 761 665 15/3 13/8

BATTELLE COLUMBUS LABS OHIO TACTEC

Miniature, Remotely Controlled Land and Water Vehicles, (U)

JUL 72 157P Pope,W. S. ;Doerschuk,D. C. ;Tierney,J. M. ;
REPT. NO. A-3983
CONTRACT: F33657-71-C-0893, ARPA Order-1541

UNCLASSIFIED REPORT

ABSTRACT: The report includes a technical assessment of selected vehicles and systems; a summary of the results of a conference on miniature, remotely controlled vehiclas held at Battelle, and conclusions and recommendations with respect to miniature-vehicle technology. The objectives of the program were to conduct a survey of existing, developmental, and conceptual miniature, R/C land and water vehicles and their associated components, and to perform a technical assessment of the vehicles identified in the survey to assist interested agencies in determining which vehicles are potentially useful for their specific missions, and what actions might be necessary to modify an existing vehicle to perform as required. (U)

DESCRIPTORS: (*VEHICLES, STATE-OF-THE-ART REVIEWS), (*ADVANCED WEAPONS, *REMOTE CONTROL), AMPHIBIOUS VEHICLES, TRACKED VEHICLES, BOATS, TERRAIN, TRAFFICABILITY, MISSION PROFILES, MOBILITY, GROUND EFFECT MACHINES, PLANNING (U)

UNCLASSIFIED

DTIC REPORT BIBLIOGRAPHY SEARCH CONTROL NO. 021533

AD- 753 829 13/3

ARMY FOREIGN SCIENCE AND TECHNOLOGY CENTER CHARLOTTESVILLE VA

Remote-Controlled Bulldozer. (U)

JUN 72 4P
REPT. NO. FSTC-HT-23-1625-72
PROJ: FSTC-T7023012301

UNCLASSIFIED REPORT

SUPPLEMENTARY NOTE: Trans. from Stroitelnye i Dorozhnye Mashiny (USSR) n10 1971, by James McVay.

ABSTRACT: Hitache Senki of Japan has produced a new radio controlled bulldozer, Model T20VR, intended for operation in boggy terrain, zones of increased radioactivity, areas of fires and contaiminated areas. The control system transmitter and receiver have a transistor circuitry and operate in the 150 megohertz band. Special solenoid activated vales are employed which operate in response to radio signals. Interlocks and an emergency stop button are integral to the control circuit. Three forward and three reverse gears are provided. Minimum turning radius is 8 meters. (Author) (U)

DESCRIPTORS: (*BULLDOZERS, *REMOTE CONTROL), RADIO EQUIPMENT, TERRAIN, HAZARDS, ENVIRONMENT, DESIGN, USSR (U)
IDENTIFIERS: TRANSLATIONS (U)

AD- 701 901 13/6 9/2

ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT CENTER
FORT BELVOIR VA

VEH DIGITAL COMPUTER PROGRAM, (U)

NOV 69 97P McKechnie,Robert N. , III;
REPT. NO. USAMERDC-1968
PROJ: DA-1-T-662705-A-012

UNCLASSIFIED REPORT

ABSTRACT: A digital computer program called VEH was written to expedite the analysis and design of vehicles. Written specifically for use in the USAMERDC electric vehicle program, it is equally applicable to mechanical vehicles. The program is written in Fortran IV on punched cards and has one main program and five subroutines. By specifying the appropriate vehicle parameters, the program will provide a definition table, horsepower-versus-speed tables, acceleration and deceleration data, and a table that will provide HP and torque requirements as functions of slope, speed, payload, and surface type. (Author) (U)

DESCRIPTORS: (*VEHICLES, COMPUTER PROGRAMS), DESIGN, ANALYSIS, PERFORMANCE(ENGINEERING), VEHICLE CHASSIS COMPONENTS, ACCELERATION, BRAKING, TORQUE, INERTIA, POWER, TERRAIN, MODELS(SIMULATIONS) (U)

IDENTIFIERS: *COMPUTER AIDED DESIGN, COMPUTERIZED SIMULATION, ELECTRIC VEHICLES (U)

AD- 807 719

NAVAL TRAINING DEVICE CENTER PORT WASHINGTON N Y

AUTOMATIC MODEL PROPULSION SYSTEM FOR 3-D
TERRAIN. (U)

DESCRIPTIVE NOTE: Technical rept.,
SEP 64 10P McKee,Thomas ;
REPT. NO. NAVTRADEVCEN-IH-21

UNCLASSIFIED REPORT

SUPPLEMENTARY NOTE:

ABSTRACT: The report introduces a novel approach to group training in tactics, and war game exercise. It describes a dynamic display produced by automatic propulsion of scale model vehicles on 3-dimensional terrain with capabilities for closed-loop operation of an automatic, programed system for maneuver control of up to 120 vehicles. (Author) (U)

DESCRIPTORS: (*MILITARY STRATEGY, DISPLAY SYSTEMS), (*TRAINING DEVICES, MODELS (SIMULATIONS)), (*PROPULSION SYSTEMS, MODELS (SIMULATIONS)), AMPHIBIOUS OPERATIONS, TERRAIN MODELS, VEHICLES, REMOTE CONTROL (U)

UNCLASSIFIED

DEPARTMENT OF DEFENSE

RESEARCH AND TECHNOLOGY WORK UNIT INFORMATION SYSTEM

REPORT ON

ROBOTIC VEHICLES (U) Army 5-C

DTIC REPORT NO. CX7419 APR 07, 1983

REQUESTED BY

C. BROWN, X46887

USER CODE: 27000

PREPARED BY

DEFENSE TECHNICAL INFORMATION CENTER
CAMERON STATION, ALEXANDRIA, VIRGINIA

(THIS PAGE IS UNCLASSIFIED)

UNCLASSIFIED

TITLE: (U) HUMAN FACTORS ENGINEERING IN SUPPORT OF AVIATION, ARMOR, COMMUNICATIONS, ENGINEER AND MISSILE EQUIPMENT

PERFORMING ORGANIZATION
DARCOM HUMAN ENGINEERING
LABORATORY ABERDEEN PG MD 21005

RESPONSIBLE GOVT ORGANIZATION
DARCOM HUMAN ENGINEERING LABS
ABERDEEN PG MD 21005

PRINCIPAL INVESTIGATOR
ERICKSON,J R

ASSOCIATE INVESTIGATOR
DAVIS,C J

TELEPHONE NUMBER
301-278-4850

CONTRACT/GRANT NUMBER

PERFORMANCE METHOD
IN-HOUSE

CONTRACT/GRANT AMOUNT
$ 0

DATE OF SUMMARY	START DATE	ESTIMATED COMPLETION DATE
01 JUL 78	JUL 64	CONT

KIND OF SUMMARY	SUMMARY SECURITY	WORK SECURITY
TERMINATED	UNCLASSIFIED	UNCLASSIFIED

SCIENTIFIC AND TECHNOLOGICAL AREAS
007500 HUMAN FACTORS ENGINEERING
009400 MAN-MACHINE RELATIONS
010700 MISSILES

PROGRAM ELEMENT:	PROJECT NO:	TASK NUMBER:
62716A	1Y762716AH70	01

KEYWORDS: (U) HUMAN FACTORS ENGINEERING ANALYSIS ;(U) MAINTAINABILITY ;(U) INFORMATION PROCESSING ;(U) AVIATION ARMOR COMMUNICATION ENGINEER MISSILE EQU

DESCRIPTORS: (U) BULLDOZERS ;(U) COMMUNICATION EQUIPMENT ;(U) COMMUNICATION AND RADIO SYSTEMS ;(U) DATA PROCESSING ;(U) DISPLAY SYSTEMS ;(U) GENERATORS ;(U) *GUIDED MISSILES ;(U) *HUMAN FACTORS ENGINEERING ;(U) *MILITARY ENGINEERING ;(U) MINELAYING EQUIPMENT

IDENTIFIERS: (U) IST ;(U) EFFECTIVENESS ;

OBJECTIVE: (U) TO PERFORM HUMAN FACTORS ENGINEERING ANALYSIS AND EXPERIMENTAL STUDIES IN SUPPORT OF MISSILES, COMMUNICATIONS, AVIATION, AND ENGINEER EQUIPMENT. TO DEVELOP ANALYTIC METHODS AND PROCEDURES FOR ASSESSING HUMAN FACTORS ENGINEERING REQUIREMENTS AND CRITERIA IN THE DEVELOPMENT OF LARGE COMPLEX SYSTEMS AND PROCUREMENT OF OFF-THE-SHELF ITEMS OF ENGINEERING EQUIPMENT. RESEARCH IN THE AREA OF HUMAN FACTORS IN MAINTAINABILITY, AVIATION EQUIPMENT, COMPLEX DISPLAYS AND INFORMATION PROCESSING FOR FIELD OPERATIONS WILL BE CONDUCTED.

APPROACH: (U) STUDIES WILL BE CONDUCTED TO DEVELOP HUMAN ENGINEERING CRITERIA FOR AIR DEFENSE AND COMMAND CONTROL DISPLAYS AND INFORMATION PROCESSING EQUIPMENT- DETERMINE HUMAN FACTORS IMPLICATIONS OF PERFORMING COMMUNICATION TASKS ON-THE-MOVE- INVESTIGATE SWITCHBOARD OPERATOR CALL HANDLING VARIABLES.

RESOURCE ESTIMATED (FUNDS IN THOUSANDS) CFY 0
CFY-1 0

CONTRACTOR ACCESS: YES ACCESSION NUMBER: DAOA4942

PROCESSING DATE: 15 SEP 76

TITLE: (U) EVALUATION OF ARMY AMMUNITION SUPP LY SYSTEM

PERFORMING ORGANIZATION
FALCON RESEARCH + DEVELOPMENT
CO 1225 SOUTH HURON STREET
DENVER CO 80223

RESPONSIBLE GOVT ORGANIZATION
DARCOM HUMAN ENGINEERING
LABORATORY ABERDEEN PROVING
GROUND MD 21005

PRINCIPAL INVESTIGATOR
DUVALL, B M

ASSOCIATE INVESTIGATOR

TELEPHONE NUMBER
3C1-278-3901

CONTRACT/GRANT NUMBER
DAAK11 79 C 0048

PERFORMANCE METHOD
CONTRACT

CONTRACT/GRANT AMOUNT
$ 89,800

DATE OF SUMMARY
20 AUG 80

START DATE
MAR 79

ESTIMATED COMPLETION DATE
FEB 80

KIND OF SUMMARY
COMPLETION

SUMMARY SECURITY
UNCLASSIFIED

WORK SECURITY
UNCLASSIFIED

SCIENTIFIC AND TECHNOLOGICAL AREAS
007500 HUMAN FACTORS ENGINEERING
009400 MAN-MACHINE RELATIONS

PROGRAM ELEMENT:
62716A

PROJECT NO:
1L162716AH70

TASK NUMBER:
00

KEYWORDS: (U) HUMAN PERFORMANCE ;(U) AMMUNITION SUPPLY ;(U) MATERIAL HANDLING EQUIP ;(U) AMMO

DESCRIPTORS: (U) AMMUNITION ;(U) ACQUISITION ;(U) EXOSKELETON (U) DATA BASES ;(U) CRANES;(U) COMPUTERS ;(U) WEATHER ;(U) VARIATIONS ;(U) TRAINING ;(U) TERRAIN ;(U) ROUGHNESS ;(U) PERFORMANCE(HUMAN);(U) PERFORMANCE(ENGINEERING);(U) MATERIALS HANDLING;(U) LABORATORIES;(U) INSTRUMENTATION ;(U) FORKLIFT VEHICLES ;(U) EXPERIMENTAL DATA

IDENTIFIERS:

OBJECTIVE: (U) SUPPORT INHOUSE RESEARCH FOR- ACQUISITION AND ANALYSIS OF EXPERIMENTAL DATA ON THE RELATIONSHIPS OF HUMAN

PERFORMANCE AND TRAINING VARIABLES AND THE DESIGN OF MATERIEL HANDLING EQUIPMENT TO MEET ROUGH TERRAIN, WEATHER, AND DAY AND NIGHT REQUIREMENTS- INVESTIGATION OF NEW AND NOVEL TECHNIQUES FOR MATERIEL HANDLING EQUIPMENT SUCH AS FORKLIFTS, CRANES, FORCE FEED BACK CONTROLS, EXOSKELETON, ETC- DEVELOPMENT OF A FIELD LABORATORY- DEVELOPMENT OF A COMPREHENSIVE AMMUNITION HANDLING HUMAN FACTIRS DATA BASE.

APPROACH: (U) A COMPUTERIZED DATA BASE OF MHE OPERATOR PEFORMANCE, BASED ON FIELD TEST DATA, WILL BE USED TO EVALUATE CURRENT ASP OPERATING PROCEDURES AND ORGANIZATION. NEW EQUIPMENT TO SUPPORT ASP/ATP OPERATIONS AND THE RETAIL DELIVERY OF AMMUNITION WILL BE TESTED, BOTH DAY AND NIGHT, AND COMPARED AGAINST THE CURRENT INVENTORY. INSTRUMENTED DATA (WHEN AVAILABLE) MAY HELP IN THE ANALYSIS OF PERFORMANCE DIFFERENCES BETWEEN SUBJECTS.

RESOURCE ESTIMATED (FUNDS IN THOUSANDS)	CFY	0
	CFY-1	0

CONTRACTOR ACCESS: YES ACCESSION NUMBER: DAOD4831

PROCESSING DATE: 10 SEP 80

TITLE: (U) AUTOMATIC RIDE CONTROL

PERFORMING ORGANIZATION	RESPONSIBLE GOVT ORGANIZATION
MOBILITY SYSTEMS LAB WARREN, MC 48090	TACOM MOBILITY SYSTEMS LAB WARREN MC 48090

PRINCIPAL INVESTIGATOR	ASSOCIATE INVESTIGATOR
CAMERON, J W	

TELEPHONE NUMBER	CONTRACT/GRANT NUMBER
313756100031246	

PERFORMANCE METHOD	CONTRACT/GRANT AMOUNT
IN-HOUSE	$ 0

DATE OF SUMMARY	START DATE	ESTIMATED COMPLETION DATE
13 DEC 71	JUN 60	DEC 71

KIND OF SUMMARY	SUMMARY SECURITY	WORK SECURITY
TERMINATED	UNCLASSIFIED	UNCLASSIFIED

SCIENTIFIC AND TECHNOLOGICAL AREAS
019400 ACTIVE ELECTROMAGNETIC RADIATORS, SENSORS & EQUIPMENT
007200 GROUND TRANSPORTATION EQUIPMENT
003700 COMBAT VEHICLES

PROGRAM ELEMENT:	PROJECT NO:	TASK NUMBER:
62601A	1G562601D263	00

KEYWORDS: (U) MOBILITY ;(U) SUSPENSION ;(U) CROSS COUNTRY MOBILITY ;(U) REMOTE SENSOR ;

DESCRIPTORS: (U) ARMORED VEHICLES ;(U) AUTOMATIC ;(U) CARGO VEHICLES ;(U) FEASIBILITY STUDIES ;(U) MOBILITY ;(U) *REMOTE CONTROL ;(U) ROUGHNESS ;(U) *DETECTORS ;(U) SHOCK(MECHANICS) ;(U) *SUSPENSION DEVICES;(U) *TERRAIN ;(U) VEHICLES ;

IDENTIFIERS: (U) COMBAT VEHICLES ;(U) CROSS COUNTRY TESTS ;(U) RIDE COMFORT

OBJECTIVE: (U) INCREASE THE CROSS-COUNTRY SPEED OF MILITARY VEHICLES BY FIVEFOLD OR SIXFOLD THROUGH DEVELOPMENT OF A REMOTE SENSOR TO DETECT BUMPS IN THE VEHICLE PATH FOR AN ACTIVE

SUSPENSION TO RAISE THE WHEELS BEFORE THE BUMP IS REACHED.

APPROACH: (U) THE DEVELOPMENT OF A PROFILE SENSOR COMPOSED OF A LASER RANGER AND A ROCKING MIRROR SERVO SYSTEM WILL PROVIDE THE FINE RESOLUTION, HIGH DATA RATE AND RANGE ACCURACY REQUIRED. THIS WILL BE SUPPLEMENTED BY A LONG RANGE MAJOR OBSTACLE SENSOR SIMILAR TO AND INTEGRATED WITH THE PROFILE SENSOR AND BY A CRUSHABILITY SENSOR WHICH WILL LIKELY UTILIZE PASSIVE MICROWAVES. UTILIZATION OF THE SENSING SYSTEM OUTPUT INFORMATION AS THE CONTROL FOR AN ACTIVE SUSPENSION SYSTEM WILL PROVIDE AUTOMATIC RIDE CONTROL.

RESOURCE ESTIMATED (FUNDS IN THOUSANDS) CFY 0
CFY-1 0

CONTRACTOR ACCESS: YES

ACCESSION NUMBER: DAOF3495

PROCESSING DATE: 31 MAR 72

TITLE: (U) TOPOGRAPHIC PRODUCTS TO SUPPORT ARMOR OPERATIONS

PERFORMING ORGANIZATION OCE ETL GEOGRPHIC SCEINCES DIV FT BELVOIR VA 22060	RESPONSIBLE GOVT ORGANIZATION OCE ETL GEOGRPHIC SCEINCES DIV FT BELVOIR VA 22060
PRINCIPAL INVESTIGATOR REIMER, A H	ASSOCIATE INVESTIGATOR
TELEPHONE NUMBER 703-664-5716	CONTRACT/GRANT NUMBER
PERFORMANCE METHOD IN-HOUSE	CONTRACT/GRANT AMOUNT $ 0

DATE OF SUMMARY 01 APR 74	START DATE JAN 72	ESTIMATED COMPLETION DATE MAR 73
KIND OF SUMMARY TERMINATED	SUMMARY SECURITY UNCLASSIFIED	WORK SECURITY UNCLASSIFIED

SCIENTIFIC AND TECHNOLOGICAL AREAS
007000 GEOGRAPHY
008400 INTELLIGENCE
011800 OPERATIONS, STRATEGY, AND TACTICS

PROGRAM ELEMENT:	PROJECT NO:	TASK NUMBER:
63	3203	01

KEYWORDS: (U) ARMOR OPERATIONS ;(U) MILITARY GEOGRAPHY;(U) TERRAIN ;(U) TERRAIN INTELLIGENCE ;(U) TOPOGRAPHY

DESCRIPTORS: (U) *ARMORED VEHICLES ;(U) COLLECTING METHODS;(U) CULTURE ;(U) FEASIBILITY STUDIES ;(U) GEOGRAPHY ;(U) IMAGES;(U) MILITARY INTELLIGENCE ;(U) PREPARATION ;(U) REMOTE CONTROL ;(U) DETECTORS ;(U) SOCIOLOGY ;(U) STANDARDS ;(U) *TERRAIN INTELLIGENCE

IDENTIFIERS: (U) ARMORED OPERATIONS;(U) FIELD ACTIVITIES ;(U) MILITARY GEOGRAPHY;(U) MILITARY PLANNING ;(U) REMOTE DETECTORS

OBJECTIVE: (U) THE OBJECTIVE IS TO DEVELOP AN EXPERIMENTAL TOPOGRAPHIC PRODUCT (OR FAMILY OF PRODUCTS) TO PROVIDE

INFORMATION ON TERRAIN AND CULTURAL CONDITIONS REQUIRED TO SUPPORT THE PLANNING AND CONDUCT OF ARMOR OPERATIONS.

APPROACH: (U) DETERMINE THE PRESENT AND NEAR FUTURE OPERATIONAL FUNCTIONS OF, AND THE TERRAIN RELEVANT MILITARY DOCTRINE GOVERNING ARMOR OPERATIONS. DETERMINE THE EFFECT OF TERRAIN ON ARMOR OPERATIONS AND THE SPECIFIC TERRAIN DATA NEEDED TO PLAN AND CONDUCT SUCH OPERATIONS. DETERMINE THE FEASIBILITY OF USING NEW IMAGE FORMING REMOTE SENSOR INFORMATION COLLECTION SYSTEMS FOR PRODUCT DEVELOPMENT AND DESIGN. DESIGN PRODUCTS AT APPROPRIATE SCALES AND SUBMIT ALTERNATIVES FOR APPROVAL. FIELD TEST AND REVISE PRODUCTS. PREPARE REPORT FOLLOWING THE FIELD TESTS. SUBMIT THE PACKAGE TO DEPARTMENT OF THE ARMY FOR ACCEPTANCE AS A STANDARD ARMY PRODUCT.

RESOURCE ESTIMATED (FUNDS IN THOUSANDS) CFY 0
CFY-1 0

CONTRACTOR ACCESS: YES ACCESSION NUMBER: DAOG8014

PROCESSING DATE: 03 JUN 74

TITLE: (U) OFF-ROAD MOBILITY AND GENERALIZED ANALYSIS %OMEGA<
DRIVE TRAIN EVALUATION PROGRAM

PERFORMING ORGANIZATION
TACOM ARMY TANK-AUTOMOTIVE
COMMAND (CONCEPT + TECHNOLOGY
DIVISION WARREN MC 48090

RESPONSIBLE GOVT ORGANIZATION
TACOM ENGINEERING SCIENCE
DIVISION MOBILITY SYSTEMS
LABORATORY WARREN MC 48090

PRINCIPAL INVESTIGATOR
WOLLAM,J M

ASSOCIATE INVESTIGATOR

TELEPHONE NUMBER
313-573-1051

CONTRACT/GRANT NUMBER

PERFORMANCE METHOD
IN-HOUSE

CONTRACT/GRANT AMOUNT
$ 0

DATE OF SUMMARY	START DATE	ESTIMATED COMPLETION DATE
08 JUL 74	JUL 73	JUN 79

KIND OF SUMMARY	SUMMARY SECURITY	WORK SECURITY
TERMINATED	UNCLASSIFIED	UNCLASSIFIED

SCIENTIFIC AND TECHNOLOGICAL AREAS
007200 GROUND TRANSPORTATION EQUIPMENT
003700 COMBAT VEHICLES

PROGRAM ELEMENT:	PROJECT NO:	TASK NUMBER:
65803A	1E865803M730	00

KEYWORDS: (U) EVALUATION ;(U) ENGINES ;(U) POWER TRAINS;(U) MODELS;(U) GRAPHICS ;(U) SOFT

DESCRIPTORS: (U) *COMPUTER PROGRAMS ;(U) *TANK ENGINES;(U) DRIVES;(U) COMBAT VEHICLES ;(U) ENGINEERS ;(U) INPUT OUTPUT DEVICES ;(U) WEIGHT;(U) GEARS ;(U) RATIOS;(U) DRIVE SPROCKETS (U) TORQUE CONVERTERS ;(U) TRANSMISSIONS(MECHANICS);(U) MOBILITY ;(U) TERRAIN ;(U) COMPUTER APPLICATIONS ;(U) GRAPHICS ;(U) MAN MACHINE SYSTEMS ;(U) COMPUTERIZED SIMULATION ;(U) DIGITAL COMPUTERS ;(U) INTERACTIONS;(U) AUTOMOTIVE VEHICLES ;(U) OFFROAD TRAFFIC ;

IDENTIFIERS: (U) DESIGN;(U) *COMPUTER AIDED DESIGN ;(U) COMPUTER

GRAPHICS ;(U) IBM 360 COMPUTERS ;(U) OMEGA COMPUTER PROGRAM ;

OBJECTIVE: (U) TO DEVELOP AN INTERACTIVE GRAPHICS PROGRAM FOR COMPUTER AIDED EVALUATION OF VEHICLE ENGINES AND POWER TRAINS. THE PROGRAM WILL ALLOW THE USER TO CHANGE VEHICLE WEIGHT, GEAR RATIOS, SPROCKET DIAMETER, FUNCTIONAL CHARACTERISTICS OF ENGINES, TORQUE CONVERTERS, TRANSMISSIONS AND SEVERAL OTHER PARAMETERS THAT AFFECT A VEHICLES PERFORMANCE AND DISPLAY THE OUTPUT ON THE GRAPHICS TERMINAL.

APPROACH: (U) TO UTILIZE TWO MODELS DEVELOPED PREVIOUSLY UNDER THE OMEGA PROJECT AND GENERATE THE NECESSARY GRAPHICS SOFTWARE TO ALLOW THE PROGRAM TO BE RUN IN A GRAPHIC MODE. THIS INTERACTIVE GRAPHICS MODE WILL ALLOW ANY ENGINEER AT TACOM TO ACCESS VEHICLE PERFORMANCE WITH DIFFERECT POWER TRAIN COMPONENTS, AND MAKE THIS ASSESSMENT IN A MATTER OF MINUTES.

RESOURCE ESTIMATED (FUNDS IN THOUSANDS) CFY 0
CFY-1 0

CONTRACTOR ACCESS: YES ACCESSION NUMBER: DAOJ3514

PROCESSING DATE: 17 SEP 74

TITLE: (U) DEVELOPMENT OF VEHICLE DYNAMICS MODEL

PERFORMING ORGANIZATION
TARADCOM ENGINEERING SCIENCE
DIVISION MOBILITY SYSTEMS LAB
WARREN MI 48090

RESPONSIBLE GOVT ORGANIZATION
TARADCOM SCIENCE + TECHNOLOGY
DIVISION, TANK-AUTOMOTIVE R+D
LAB WARREN MI 48090

PRINCIPAL INVESTIGATOR
BECK, R DR

ASSOCIATE INVESTIGATOR
W M LINS

TELEPHONE NUMBER
313-573-1574

CONTRACT/GRANT NUMBER

PERFORMANCE METHOD
IN-HOUSE

CONTRACT/GRANT AMOUNT
$ 0

DATE OF SUMMARY	START DATE	ESTIMATED COMPLETION DATE
13 OCT 76	JUL 72	JUL 74

KIND OF SUMMARY	SUMMARY SECURITY	WORK SECURITY
TERMINATED	UNCLASSIFIED	UNCLASSIFIED

SCIENTIFIC AND TECHNOLOGICAL AREAS
003700 COMBAT VEHICLES
015C00 SOLID MECHANICS

PROGRAM ELEMENT:	PROJECT NO:	TASK NUMBER:
61102A	1F161102B52A	00

KEYWORDS: (U) VEHICLE DYNAMICS ;(U) RIDE ;(U) MOBILITY ;(U) HYBRID COMPUTER SIMULATION

DESCRIPTORS: (U) *ANALOG DIGITAL COMPUTERS;(U) *DYNAMICS ;(U) HUMAN FACTORS ENGINEERING ;(U) IMPACT;(U) MATHEMATICAL MODELS (U) MOTION;(U) SIMULATION ;(U) SURFACE ROUGHNESS ;(U) TERRAIN (U) *VEHICLES

IDENTIFIERS: (U) COMPUTER AIDED DESIGN ;(U) DESIGN;

OBJECTIVE: (U) TO DEVELOP A GENERALIZED THREE DIMENSIONAL DYNAMIC ANALYSIS METHODOLOGY TO FACILITATE PARAMETRIC VEHICLE DESIGN STUDIES.

APPROACH: (U) THE APPROACH CONSISTS OF CREATING A COMPUTER SIMULATION FEATURING A THREE DIMENSIONAL CHARACTERIZATION OF VEICLE RESPONSE TO IMPACT FORCES GENERATED AT THE VEHICLE CONTACT WHEN TRAVERSING ROUGH TERRAIN. A SENSITIVITY ANALYSIS WILL BE CONDUCTED TO EXAMINE THE INDIVIDUAL SUBMODELS AND THEIR EFFECT ON THE RIDE LIMITING SPEED.

RESOURCE ESTIMATED (FUNDS IN THOUSANDS) CFY 0
CFY-1 0

CONTRACTOR ACCESS: YES ACCESSION NUMBER: DAOK3501

PROCESSING DATE: 29 NOV 78

TITLE: (U) COMMAND AND CONTROL TRAINING VEHICLE (CCTV)

PERFORMING ORGANIZATION
TARADCOM TANK AUTOMOTIVE
RESEARCH AND DEVELOPMENT
COMMAND WARREN MI 48090

RESPONSIBLE GOVT ORGANIZATION
DARCOM PROJECT MANAGER FOR
TRAINING DEVICES, NAVAL
TRAINING EQUIPMENT CENTER
ORLANDO FL 32813

PRINCIPAL INVESTIGATOR
BLANKENSHIP, E

ASSOCIATE INVESTIGATOR

TELEPHONE NUMBER
313-573-1455

CONTRACT/GRANT NUMBER

PERFORMANCE METHOD
IN-HOUSE

CONTRACT/GRANT AMOUNT
$ 0

DATE OF SUMMARY	START DATE	ESTIMATED COMPLETION DATE
01 APR 79	MAY 76	SEP 77

KIND OF SUMMARY	SUMMARY SECURITY	WORK SECURITY
TERMINATED	UNCLASSIFIED	UNCLASSIFIED

SCIENTIFIC AND TECHNOLOGICAL AREAS
009400 MAN-MACHINE RELATIONS
011800 OPERATIONS, STRATEGY, AND TACTICS

PROGRAM ELEMENT:	PROJECT NO:	TASK NUMBER:
64715A	1X764715D572	0

KEYWORDS: (U) LIGHTWEIGHT VEHICLE FOR ARMOR AND INFANTRY UNITS;

DESCRIPTORS: (U) MECHANIZATION ;(U) INFANTRY ;(U) REQUIREMENTS (U) TERRAIN ;(U) LEADERSHIP TRAINING ;(U) ARMOR ;(U) GROUND VEHICLES ;(U) REPORTS ;(U) RELIABILITY ;

IDENTIFIERS:

OBJECTIVE: (U) TO PROVIDE ARMOR AND MECHANIZED INFANTRY UNITS WITH A SMALL, LIGHTWEIGHT, EASY-TO-MAINTAIN VEHICLE WHICH WILL BE UTILIZED FOR LEADERSHIP TRAINING DURING COMMAND AND CONTROL TRAINING EXERCISES WHILE KEEPING MANEUVER DAMAGE TO A MINIMUM.

APPROACH: (U) COMMERCIALLY AVAILABLE, ALL-TERRAIN VEHICLES (ATVS) PURCHASED FROM TWO MANUFACTURERS, AND MODIFIED M151A1 VEHICLES WILL COMPETE DURING A CONCURRENT DT/OT II TO DETERMINE THE VEHICLE WHICH BEST SATISFIES THE REQUIREMENT. FOLLOWING VEHICLE SELECTION, APPROXIMATELY 1800 VEHICLES WILL BE MANUFACTURED/MODIFIED FOR FIELD USE.

RESOURCE ESTIMATED (FUNDS IN THOUSANDS) CFY 0
CFY-1 0

CONTRACTOR ACCESS: YES ACCESSION NUMBER: DAOU4998

PROCESSING DATE: 09 MAY 79

APPROACH: (U) COMMERCIALLY AVAILABLE, ALL-TERRAIN VEHICLES (ATVS) PURCHASED FROM TWO MANUFACTURERS, AND MODIFIED M151A1 VEHICLES WILL COMPETE DURING A CONCURRENT DT/OT II TO DETERMINE THE VEHICLE WHICH BEST SATISFIES THE REQUIREMENT. FOLLOWING VEHICLE SELECTION, APPROXIMATELY 1800 VEHICLES WILL BE MANUFACTURED/MODIFIED FOR FIELD USE.

RESOURCE ESTIMATED (FUNDS IN THOUSANDS) CFY 0
CFY-1 0

CONTRACTOR ACCESS: YES ACCESSION NUMBER: DAOU4998

PROCESSING DATE: 09 MAY 79

TITLE: (U) TERRAIN ANALYSIS DEMONSTRATOR

PERFORMING ORGANIZATION
OCE ETL RESEARCH INSTITUTE ETL
RI-B FT BELVOIR VA 22060

RESPONSIBLE GOVT ORGANIZATION
OCE ETL RESEARCH INSTITUTE
ETL-RI-B FT BELVOIR VA 22060

PRINCIPAL INVESTIGATOR
ZIMMERMAN, B.

ASSOCIATE INVESTIGATOR

TELEPHONE NUMBER
7036644086

CONTRACT/GRANT NUMBER

PERFORMANCE METHOD
IN-HOUSE

CONTRACT/GRANT AMOUNT
$ 0

DATE OF SUMMARY
27 JAN 83

START DATE
OCT 82

ESTIMATED COMPLETION DATE
SEP 85

KIND OF SUMMARY
NEW

SUMMARY SECURITY
UNCLASSIFIED

WORK SECURITY
UNCLASSIFIED

SCIENTIFIC AND TECHNOLOGICAL AREAS
004200 COMPUTERS
008400 INTELLIGENCE

PROGRAM ELEMENT: 62707A
PROJECT NO: 4A162707A855
TASK NUMBER: C

KEYWORDS: (U) ARTIFICIAL INTELLIGENCE ;(U) ROBOTICS ;(U) TERRAIN ANALYSIS ;(U) RECONNAISSANCE ;

DESCRIPTORS: (U) AGREEMENTS ;(U) ARMOR ;(U) ARMY EQUIPMENT ;(U) ARTIFICIAL INTELLIGENCE ;(U) AUTOMATA ;(U) BASE LINES ;(U) COMPUTER PROGRAMS ;(U) COMPUTERS ;(U) CONTRACTS ;(U) DATA BASES (U) DEMONSTRATIONS ;(U) DETECTORS ;(U) ENGINEERS ;(U) FUNCTIONS (U) HUMAN FACTORS ENGINEERING ;(U) INTEGRATED SYSTEMS;(U) LABORATORIES;(U) MICROCOMPUTERS ;(U) MULTICHANNEL COMMUNICATIONS ;(U) PLANNING ;(U) RECONNAISSANCE ;(U) REQUIREMENTS;(U) TERRAIN (U) TEST FACILITIES ;(U) TOPOGRAPHY ;(U) VEHICLES

IDENTIFIERS:

OBJECTIVE: (U) TO ESTABLISH THE TECHNICAL REQUIREMENTS FOR

IMPLEMENTING A ROBOTIC RECONNAISSANCE VEHICLE DEMONSTRATOR WITH TERRAIN ANALYSIS. THIS WORK WILL SPECIFY THE BASE LINE HARDWARE, SOFTWARE, DATA BASE, AND SYSTEM INTEGRATION FUNCTIONAL REQUIREMENTS SO THAT A FIELDABLE, WORKING DEMONSTRATION VEHICLE CAN BE CONSTRUCTED.

APPROACH: (U) IN-HOUSE AND CONTRACT STUDIES WILL DETERMINE THE AVAILABILITY AND APPLICABILITY OF VARIOUS GRAPHICS/IMAGE PROCESSING SOFTWARE MODULES; AVAILABILITY AND FEASIBILITY OF VARIOUS TOPOGRAPHIC/TERRAIN DATA BASES FOR PROPOSED TEST AREAS; SYSTEM INTEGRATION REQUIREMENTS FOR IMPLEMENTING THE MULTIPROCESSOR, MICROCOMPUTER BASED COMPUTER SYSTEMS AND THE VARIOUS RECONNAISSANCE SENSORS; AND THE MULTI-CHANNEL COMMUNICATIONS REQUIREMENTS.

RESOURCE ESTIMATED (FUNDS IN THOUSANDS) CFY 300
CFY-1 0

CONTRACTOR ACCESS: YES ACCESSION NUMBER: DA300858

PROCESSING DATE: 31 JAN 83

TITLE: (U) ROBOTIC VEHICLE ROUTE PLANNING

PERFORMING ORGANIZATION
OCE ETL RESEARCH INSTITUTE ETL
RI-B FT BELVOIR VA 22060

RESPONSIBLE GOVT ORGANIZATION
OCE ETL RESEARCH INSTITUTE
ETL-RI-B FT BELVOIR VA 22060

PRINCIPAL INVESTIGATOR
LEIGHTY, R. D.

ASSOCIATE INVESTIGATOR

TELEPHONE NUMBER
7036643220

CONTRACT/GRANT NUMBER

PERFORMANCE METHOD
IN-HOUSE

CONTRACT/GRANT AMOUNT
$ 0

DATE OF SUMMARY	START DATE	ESTIMATED COMPLETION DATE
03 FEB 83	FEB 83	SEP 83

KIND OF SUMMARY	SUMMARY SECURITY	WORK SECURITY
NEW	UNCLASSIFIED	UNCLASSIFIED

SCIENTIFIC AND TECHNOLOGICAL AREAS
004200 COMPUTERS
008400 INTELLIGENCE

PROGRAM ELEMENT:	PROJECT NO:	TASK NUMBER:
61101A	4A161101A91D	01

KEYWORDS: (U) ROBOTICS ;(U) TERRAIN ANALYSIS ;(U) ARTIFICIAL INTELLIGENCE ;(U) ROUTE PLANNING ;

DESCRIPTORS: (U) ALGORITHMS ;(U) ARTIFICIAL INTELLIGENCE ;(U) AUTOMATA ;(U) COLORS;(U) COMPUTER PROGRAMS ;(U) COMPUTERS ;(U) DATA BASES ;(U) DIGITAL SYSTEMS ;(U) ELEVATION ;(U) FLOORS;(U) HYDROLOGY ;(U) INDUSTRIAL PLANTS ;(U) MONITORS ;(U) OPERATORS(PERSONNEL) ;(U) PLANNING ;(U) RECONNAISSANCE ;(U) SOILS ;(U) SURFACES ;(U) TERRAIN ;(U) TWO DIMENSIONAL ;(U) VEGETATION (U) VEHICLES

IDENTIFIERS:

OBJECTIVE: (U) CURRENT ROBOT ROUTE PLANNING ALGORITHMS ARE DESIGNED TO LOCATE PATHS AROUND OBSTACLES ON A TWO-DIMENSIONAL

SURFACE (FACTORY FLOOR, TABLE TOP, ETC.). THIS EFFORT WILL DEVELOP THE CAPABILITY FOR PLANNING ROUTES IN THREE-DIMENSIONS FROM DIGITAL TERRAIN DATA BASES (TERRAIN ELEVATIONS, VEGETATION, SOILS, HYDROLOGY, TRANSPORTATION ROUTES, ETC.).

APPROACH: (U) A COMPUTER PROGRAM WILL BE PREPARED FOR ROBOTIC VEHICLE ROUTE PLANNING. THE PROGRAM WILL USE DIGITAL TERRAIN DATA BASES AND AN INTERACTIVE DIGITAL COMPUTER/VIDEO PROCESSOR COMBINATIONS. SELECTED TERRAIN DATA BASE DATA WILL BE DISPLAYED ON A COLOR MONITOR AND AN OPERATOR CAN SELECT A START POINT AND AN END POINT FOR THE ROUTE FROM THE DISPLAY WITH A CURSOR. THE COMPUTER WILL FIND THE BEST ROUTE BETWEEN THESE POINTS AND PLOT THE ROUTE ON THE COLOR DISPLAY. ENHANCEMENTS TO THIS BASIC PROGRAM: (1) OPERATOR CAPABILITY TO INDICATE INTERMEDIATE POINTS THROUGH WHICH THE ROUTE MUST PASS AND (2) OPERATOR CAPABILITY TO EDIT (MODIFY) THE COMPUTED AND DISPLAYED ROUTE.

RESOURCE ESTIMATED (FUNDS IN THOUSANDS)	CFY	49
	CFY-1	0

CONTRACTOR ACCESS: YES　　ACCESSION NUMBER: DA300704

PROCESSING DATE: 09 FEB 83

TITLE: (U) AUTOMATIC PICTORIAL PATTERN RECOGNITION TECHNIQUES FOR USE IN MULTI-SENSOR ENVIRONMENTS

PERFORMING ORGANIZATION
OHIO STATE UNIV RESEARCH FOUNDATION COLUMBUS OHIO

RESPONSIBLE GOVT ORGANIZATION
AF OFFICE OF SCIENTIFIC RESEARCH DIR OF MATHEMATICAL INFO SCIENCES BLDG 410, BOLLING AFB, DC 20332

PRINCIPAL INVESTIGATOR
BREEDING K J

ASSOCIATE INVESTIGATOR

TELEPHONE NUMBER

CONTRACT/GRANT NUMBER
AFOSR-71-2048

PERFORMANCE METHOD
GRANT

CONTRACT/GRANT AMOUNT
$ 273,991

DATE OF SUMMARY
30 SEP 81

START DATE
JAN 70

ESTIMATED COMPLETION DATE
MAR 76

KIND OF SUMMARY
COMPLETION

SUMMARY SECURITY
UNCLASSIFIED

WORK SECURITY
UNCLASSIFIED

SCIENTIFIC AND TECHNOLOGICAL AREAS
011900 OPTICAL DETECTION

PROGRAM ELEMENT:
61102F

PROJECT NO:
9769

TASK NUMBER:
02

KEYWORDS:

DESCRIPTORS: (U) *AIR FORCE OPERATIONS ;(U) AUTOMATA ;(U) DIGITAL SYSTEMS ;(U) *LOGISTICS ;(U) MATHEMATICAL MODELS ;(U) NETWORKS (U) *REMOTE CONTROL ;(U) TERRAIN ;(U) VEHICLES ;

IDENTIFIERS: (U) SIGNAL PROCESSING ;

OBJECTIVE: (U) THE COMPLEXITY, VOLUME, AND RATE OF RECONNAISSANCE AND SURVEILLANCE DATA IS EVER INCREASING. THE ABILITY TO COPE WITH THIS PROBLEM RESTS IN THE AUTOMATION OF SOME, IF NOT ALL, OF THE DATA ANALYSIS. THIS IS ALSO TRUE OF INFLIGHT DATA THAT THE PILOT IS REQUIRED TO ANALYZE. THIS RESEARCH IS CONCERNED WITH THE

DEVELOPMENT OF MEANS FOR AUTOMATIC IDENTIFICATION OF THREE DIMENSIONAL OBJECTS FROM OPTICAL IMAGES AND FROM VARIOUS OTHER TYPES OF REMOTELY SENSED INFORMATION. THE TYPES OF OBJECTS CONSIDERED ARE GENERALLY COMPLEX MAN-MADE STRUCTURES WHICH MAY IN SOME CASES BE IMBEDDED IN A CLUTTERED BACKGROUND. THIS RESEARCH IS A CONTINUATION OF RESEARCH IN PROGRESS RELATING TO AUTOMATIC IDENTIFICATION OF AIRCRAFT TYPES FROM TELEVISION IMAGES. TO DATE, THIS PROGRAM HAS DEMONSTRATED THE ABILITY OF A DIGITAL COMPUTER TO ACHIEVE AN IDENTIFICATION ERROR RATE EQUAL TO ROUGHLY ONE-HALF THE RATE OBSERVED IN HUMAN CLASSIFICATION OF THE SAME IMAGES. THE RESEARCH PROPOSED FOR THE NEXT PHASE OF THIS INVESTIGATION FALLS INTO THREE BASIC CATEGORIES. FIRST, THE ALGORITHMS AND HARDWARE DEVELOPED UNDER THIS GRANT IN PAST YEARS WILL BE APPLIED TO VIDEO IMAGES ACQUIRED AT A LOCAL AIRPORT TO DETERMINE HOW EFFECTIVE THE SYSTEM IS IN A REAL ENVIRONMENT. THE SECOND CATEGORY OF PROPOSED RESEARCH IS AN INVESTIGATION OF TECHNIQUES FOR ACQUIRING INTERESTING TARGETS IN A CLUTTERED FIELD OF VIEW SUCH AS MIGHT BE FOUND IN AIR TO GROUND PHOTOGRAPHS. THE LAST AREA OF INTEREST IS THE DEVELOPMENT OF EFFECTIVE ARRAY PROCESSING TECHNIQUES AND TRANSFORMS FOR PERFORMING RECOGNITION DIRECTLY ON SUCH A PROCESSOR AS THAT CURRENTLY UNDER CONSTRUCTION. THESE TASKS REPRESENT A FEW STEPS TOWARD THE OVERALL GOAL OF REALIZING A USEFUL SYSTEM TO AUGMENT OR REPLACE HUMAN OBSERVERS IN REAL-TIME PATTERN RECOGNITION PROBLEMS REQUIRING ACCURATE CLASSIFICATION OF VARIOUS TYPES OF THREE-DIMENSIONAL OBJECTS.

APPROACH: (U) NONE

RESOURCE ESTIMATED (FUNDS IN THOUSANDS)	CFY	0
	CFY-1	0

CONTRACTOR ACCESS: YES   ACCESSION NUMBER: DF029410

PROCESSING DATE: 31 OCT 81

TITLE: (U) ARCTIC SURFACE EFFECT VEHICLE (SEV)-AERODYNAMICS

PERFORMING ORGANIZATION	RESPONSIBLE GOVT ORGANIZATION
NAVAL SHIP R+D CENTER SYSTEMS DEVELOP. DEPT. 1132 BETHESDA, MD. 20034	DEFENSE ADVANCED RESEARCH PROJECTS AGENCY ARLINGTON VA 22209

PRINCIPAL INVESTIGATOR	ASSOCIATE INVESTIGATOR
HARRY, C W	MAGUIRE, W B

TELEPHONE NUMBER	CONTRACT/GRANT NUMBER
202-227-1713	

PERFORMANCE METHOD	CONTRACT/GRANT AMOUNT
IN-HOUSE	$ 0

DATE OF SUMMARY	START DATE	ESTIMATED COMPLETION DATE
01 MAY 73	JUL 70	MAY 73

KIND OF SUMMARY	SUMMARY SECURITY	WORK SECURITY
TERMINATED	UNCLASSIFIED	UNCLASSIFIED

SCIENTIFIC AND TECHNOLOGICAL AREAS
000500 AERODYNAMICS
019000 CONTROL ANALYSIS AND THEORY

PROGRAM ELEMENT:	PROJECT NO:	TASK NUMBER:
62105E	3N10	ARPA

KEYWORDS: (U) NON-MILITARY APPLICATION:ARCTIC TRANSPORTATION (U) SEV PERFORMANCE ;(U) SEV DYNAMICS;

DESCRIPTORS: (U) AERODYNAMIC CHARACTERISTICS ;(U) ARCTIC REGIONS ;(U) CONTROL ;(U) *GROUND EFFECT MACHINES ;(U) MATHEMATICAL MODELS ;(U) COMPUTER PROGRAMMING ;(U) STABILITY ;(U) TERRAIN ;(U) WIND TUNNEL MODELS;

IDENTIFIERS: (U) COMPUTER AIDED DESIGN ;(U) SURFACE EFFECT VEHICLES ;(U) DESIGN;

OBJECTIVE: (U) TO DEVELOP A SIX-DEGREE-OF-FREEDOM MATHEMATICAL DYNAMICS SIMULATION MODEL FOR THE ARCTIC SEV. TO DETERMINE THE PERFORMANCE CHARACTERISTICS OF LARGE SEV'S AND EVALUATE

CONCEPTUAL DESIGNS. THE METHODS OF PROVIDING ADEQUATE STABILITY AND CONTROL UNDER ARCTIC CONDITIONS WILL BE DETERMINED.

APPROACH: (U) COLLECT AVAILABLE INFORMATION ON SEV AERODYNAMICS, STABILITY AND CONTROL, VEHICLE DYNAMICS, AND PERFORMANCE. FROM THIS DATA BASE A SIMULATION MODEL WILL BE BUILT IN STAGES. A 3 DEGREE-OF-FREEDOM SIMULATION MODEL WILL BE EXPANDED TO 6 DEGREES BY ADDING CUSHION DYNAMICS. THIS WILL BE COMBINED WITH AN ARCTIC TERRAIN MODEL. A VEHICLE PERFORMANCE PROGRAM WILL BE DEVELOPED TO HELP ESTABLISH SEV PERFORMANCE CRITERIA. ANALYTICAL EMPIRICAL PREDICTION TECHNIQUES WILL BE USED TO DEVELOP A COMPUTERIZED AERODYNAMIC FORCE AND MOMENT PROGRAM TO EVALUATE STABILITY AND CONTROL. THIS PROGRAM, IN CONJUNCTION WITH THE VEHICLE DYNAMICS PROGRAM, WILL BE USED TO ESTABLISH SEV MANEUVERING REQUIREMENTS.

RESOURCE ESTIMATED (FUNDS IN THOUSANDS)	CFY	0
	CFY-1	0

CONTRACTOR ACCESS: YES   ACCESSION NUMBER: DN110315

PROCESSING DATE: 11 MAY 73

TITLE: (U) NEV MANIPULATOR

PERFORMING ORGANIZATION
NAVAL UNDERSEA CENTER B512 SAN
DIEGO CALIF 92132

RESPONSIBLE GOVT ORGANIZATION
SPACE NUCLEAR SYSTEMS OFFICE
NEVADA EXTENSION P.O. BOX 1
JACKASS FLATS NEV 89023

PRINCIPAL INVESTIGATOR
UHRICH, R W

ASSOCIATE INVESTIGATOR
MUNSON, A E

TELEPHONE NUMBER
714-225-7630

CONTRACT/GRANT NUMBER

PERFORMANCE METHOD
IN-HOUSE

CONTRACT/GRANT AMOUNT
$ 0

DATE OF SUMMARY
01 NOV 72

START DATE
APR 72

ESTIMATED COMPLETION DATE
JUL 72

KIND OF SUMMARY
COMPLETION

SUMMARY SECURITY
UNCLASSIFIED

WORK SECURITY
UNCLASSIFIED

SCIENTIFIC AND TECHNOLOGICAL AREAS
009200 MACHINERY AND TOOLS
007700 HYDRAULIC AND PNEUMATIC EQUIPMENT
009400 MAN-MACHINE RELATIONS

PROGRAM ELEMENT: 0
PROJECT NO: 0
TASK NUMBER: 0

KEYWORDS: (U) LPS 7-259 ;(U) INV-LINEAR LINKAGE MANIPULATOR;(U) MANIPULATORS;(U) CURV ;(U) NEV ;

DESCRIPTORS: (U) CONTROL PANELS ;(U) DESERTS ;(U) HANDLING ;(U) HAZARDS ;(U) HYDRAULIC EQUIPMENT ;(U) *MACHINES ;(U) *MACHINE TOOLS ;(U) MOTION;(U) NUCLEAR REACTORS ;(U) PACKAGING ;(U) RADIO EQUIPMENT ;(U) *REMOTE CONTROL ;(U) TERRAIN ;(U) VALVES;(U) VEHICLES

IDENTIFIERS: (U) *MANIPULATORS;(U) VEHICLE ;(U) DESIGN;

OBJECTIVE: (U) A MANIPULATOR, VALVE PACKAGE AND CONTROL BOX ARE TO BE DESIGNED, FABRICATED AND DELIVERED FOR USE ON THE NUCLEAR

ROCKET DEVELOPMENT STATION EMERGENCY VEHICLE (NEV). THE NEV IS A RADIO CONTROLLED ALL-TERRAIN VEHICLE FOR THE PURPOSE OF EMERGENCY SURVEILLANCE AND WORK IN POTENTIALLY DANGEROUS AREAS. THE MANIPULATOR MUST BE CAPABLE OF LIFTING 50 POUNDS AT THE REACH OF 51 INCHES.

APPROACH: (U) AN IMPROVED VERSION OF THE CURV LINKAGE MANIPULATOR IS TO BE DESIGNED AND FABRICATED. THE IMPROVEMENTS WILL BE IN RUGGEDNESS, RANGE OF MOTIONS, AND COMPATIBILITY WITH A DESERT ENVIRONMENT.

RESOURCE ESTIMATED (FUNDS IN THOUSANDS)	CFY	0
	CFY-1	0

CONTRACTOR ACCESS: YES ACCESSION NUMBER: DN234865

PROCESSING DATE: 30 MAY 73

TITLE: (U) OCULOVESTIBULAR EFFECTS ON VISUAL PERFORMANCE IN MOVING MILITARY SYSTEMS: STABILIZED VIEWING DEVICES

PERFORMING ORGANIZATION	RESPONSIBLE GOVT ORGANIZATION
NAVAL AEROSPACE MED RES LAB BIOLOGICAL SCIENCES DEPT. PENSACOLA, FL 32508	NAVAL MEDICAL RES AND DEV COM. NATIONAL NAVAL MED CTR BETHESDA, MD 20014

PRINCIPAL INVESTIGATOR	ASSOCIATE INVESTIGATOR
HIXSON, W C	GUEDRY, F E

TELEPHONE NUMBER	CONTRACT/GRANT NUMBER
904-452-4456	

PERFORMANCE METHOD	CONTRACT/GRANT AMOUNT
IN-HOUSE	$ 0

DATE OF SUMMARY	START DATE	ESTIMATED COMPLETION DATE
30 SEP 77	JUL 73	SEP 77

KIND OF SUMMARY	SUMMARY SECURITY	WORK SECURITY
COMPLETION	UNCLASSIFIED	UNCLASSIFIED

SCIENTIFIC AND TECHNOLOGICAL AREAS
009400 MAN-MACHINE RELATIONS
002400 BIOENGINEERING
001300 AIRCRAFT

PROGRAM ELEMENT:	PROJECT NO:	TASK NUMBER:
63706N	M0095	M0095PN008

KEYWORDS: (U) HUMAN SUBJECTS ;(U) STABILIZED VIEWING DEVICES (U) MOTION;(U) MILITARY VEHICLES ;(U) VISUAL PERFORMANCE;(U) OCULOVESTIBULAR INTERACTION CIVAPP ;(U) SEARCH AND RESCUE

DESCRIPTORS: (U) DYNAMICS ;(U) MOTION;(U) MOVING TARGET INDICATORS;(U) *OPERATORS(PERSONNEL) ;(U) *OPTICAL TRACKING ;(U) PERFORMANCE(HUMAN);(U) RESCUES ;(U) STABILIZED PLATFORMS ;(U) SURFACE TARGETS ;(U) *TARGET ACQUISITION;(U) TARGET RECOGNITION (U) TERRAIN ;(U) TRAINING ;(U) VESTIBULAR APPARATUS ;(U) *VISUAL ACUITY ;(U) *VISUAL PERCEPTION

IDENTIFIERS:

OBJECTIVE: (U) THE MILITARY IS DEVELOPING A VARIETY OF OPTICAL VIEWING DEVICES WHICH CONTAIN INTERNAL STABILIZATION MECHANISMS TO MINIMIZE TARGET BLUR CAUSED BY VIBRATION OF THE OBSERVATION VEHICLE/AIRCRAFT. THOUGH THESE DEVICES IMPROVE VISUAL ACUITY, SEVERAL FIELD TEST-AND-EVALUATION GROUPS HAVE REPORTED THE OCCASIONAL INCIDENCE OF AIRSICKNESS SIDE EFFECTS DURING AIR-TO GROUND OBSERVATION. THE PROJECT OBJECTIVES WERE (1) TO DEVELOP A PERFORMANCE-BASED EXPERIMENTAL PLAN THAT WOULD PERMIT A VARIETY OF STABILIZED OPTICAL VIEWING DEVICES TO BE EVALUATED UNDER INFLIGHT OPERATING CONDITIONS, AND (2) TO UTILIZE THE EXPERIMENTAL PLAN TO ESTABLISH THE NAUSEOGENIC EFFECTS OF THE STABILIZATION FEATURE PROPER USING ONE OF THE MORE COMMON MILITARY VIEWING DEVICES AS THE TEST DEVICE.

APPROACH: (U) BECAUSE OF THE JOINT ARMY/NAVY INTEREST IN THE PROBLEM, A COOPERATIVE RESEARCH PROGRAM WAS DEVELOPED BY NAVY INVESTIGATORS AT NAMRL AND ARMY INVESTIGATORS AT USAARL TO IMPLEMENT THE PROJECT OBJECTIVES. A PROTOTYPE EXPERIMENTAL PLAN WAS DEVELOPED TO MEASURE VISUAL ACUITY AND MONITOR NAUSEOGENIC EFFECTS OF OBSERVERS USING AN XM-76 STABILIZED VIEWING DEVICE WHILE FLYING VARIOUS MANEUVERS OVER AN INSTRUMENTED TARGET RANGE IN UH-1 HELICOPTERS. IN ADDITION, A SERIES OF LABORATORY TESTS WAS DEVELOPED AND APPLIED TO THE FLIGHT SUBJECTS TO ASSESS VISUAL AND VESTIBULAR FUNCTION AND MOTION SICKNESS SUSCEPTIBILITY ON AN INDIVIDUAL SUBJECT BASIS.

RESOURCE ESTIMATED (FUNDS IN THOUSANDS) CFY 0
CFY-1 0

CONTRACTOR ACCESS: YES ACCESSION NUMBER: DN240026

PROCESSING DATE: 12 OCT 77

TITLE: (U) VISUAL AND MOTION SIMULATION SYSTEM FOR OFF-ROAD VEHICLE OPERATOR TRAINING

PERFORMING ORGANIZATION
NAVAL TRAINING EQUIPMENT CENTER
ELECTRONICS AND ACOUSTICS LAB
ORLANDO, FL 32813

RESPONSIBLE GOVT ORGANIZATION
NAVAL SEA SYSTEMS COMMAND
RESEARCH AND TECHNOLOGY DIR
WASHINGTON, D. C. 20360

PRINCIPAL INVESTIGATOR
MCKECHNIE, J C N-212

ASSOCIATE INVESTIGATOR
MANFREDI, U N-214

TELEPHONE NUMBER
305-646-4696

CONTRACT/GRANT NUMBER

PERFORMANCE METHOD
IN-HOUSE

CONTRACT/GRANT AMOUNT
$ 0

DATE OF SUMMARY
21 JAN 77

START DATE
JUL 75

ESTIMATED COMPLETION DATE
SEP 76

KIND OF SUMMARY
TERMINATED

SUMMARY SECURITY
UNCLASSIFIED

WORK SECURITY
UNCLASSIFIED

SCIENTIFIC AND TECHNOLOGICAL AREAS
005400 MAN-MACHINE RELATIONS
008000 INDUSTRIAL PROCESSES
011800 OPERATIONS, STRATEGY, AND TACTICS

PROGRAM ELEMENT: 62757N
PROJECT NO: F55522
TASK NUMBER: SF55522301

KEYWORDS: (U) COMBAT VEHICLES ;(U) SIMULATION ;(U) TRAINING ;(U) MOTION SYSTEM ;(U) VISUAL SYSTEM ;(U) TRAINING DEVICE TECHNOLOGY ;

DESCRIPTORS: (U) AIR CUSHION VEHICLES ;(U) CATHODE RAY TUBES ;(U) CONTOURS ;(U) DETECTORS ;(U) DISPLAY SYSTEMS ;(U) ENVIRONMENTS (U) IMAGES;(U) INTERFACES ;(U) PROTOTYPES ;(U) SIMULATION ;(U) SPECIFICATIONS ;(U) TELEVISION CAMERAS;(U) TERRAIN ;(U) TRAINEES ;(U) VISION;(U) WEAPON SYSTEMS ;(U) *TANKS(COMBAT VEHICLES) ;(U) *AMPHIBIOUS VEHICLES ;(U) *TRAINING DEVICES ;(U) *TERRAIN MODELS ;(U) THREE DIMENSIONAL ;(U) MARINE CORPS PERSONNEL ;(U) EQUATIONS OF MOTION ;(U) HYDROFOIL CRAFT ;(U) FLUIDICS ;(U) FEASIBILITY

STUDIES ;(U) MOTION;(U) *DRIVERS(PERSONNEL)

IDENTIFIERS: (U) LVTP-7 VEHICLES ;(U) M-48 TANKS ;(U) M-60 TANKS ;

OBJECTIVE: (U) DEVELOP VISUAL SIMULATION AND VEHICLE MOTION SIMULATION SUBSYSTEMS TO PRESENT THE VISUAL AND TERRAIN ENVIRONMENT AS PRESENTED TO THE OPERATOR/DRIVER OF THE M48 AND M60 TANK, THE LVTP-7 AMPHIBIOUS VEHICLE, AND OTHER MARINE CORPS TACTICAL MOTOR VEHICLES. THE PROTOTYPE COMPONENTS WILL BE ASSEMBLED INTO AN EXPERIMENTAL SYSTEM IN ORDER TO DETERMINE FEASIBILITY. FROM THE TESTS AND EVALUATIONS, TRAINER DESIGN CRITERIA WILL BE ESTABLISHED FOR INCORPORATION INTO PERFORMANCE SPECIFICATION FOR PROPOSED OPERATOR/DRIVER AND WEAPON SYSTEM TRAINERS. TRAINING OF DRIVERS USING ACTUAL COMBAT VEHICLES IS EXPENSIVE AND REMOVES THESE VEHICLES FROM READY FOR COMBAT STATUS.

APPROACH: (U) MULTIPLE PNEUMATIC 3-D TERRAIN CONTOUR SENSORS, EACH REPRESENTING A GROUND CONTACT POINT OF THE SIMULATED VEHICLE, WILL BE DESIGNED TO PROVIDE INPUTS TO MOTION COMPUTER AND INCORPORATED INTO EXPERIMENTAL SYSTEM. VEHICLE EQUATIONS OF MOTION WILL BE PROGRAMED, AND DEBUGGED FOR SYSTEM INTERFACE. AN EXPERIMENTAL SYSTEM WILL BE ASSEMBLED CONSISTING OF TV CAMERA, 3 D TERRAIN MODEL, VIRTUAL IMAGE DISPLAY USING A CRT DISPLAY, COMPUTER AND A TRAINEE STATION MOCKUP. THE SYSTEM WILL BE TESTED, EVALUATED, AND DEMONSTRATED. FINAL TECHNICAL REPORT WILL DOCUMENT ALL WORK.

RESOURCE ESTIMATED (FUNDS IN THOUSANDS) CFY 0
CFY-1 0

CONTRACTOR ACCESS: YES ACCESSION NUMBER: DN694001

PROCESSING DATE: 09 MAR 77

TITLE: (U) STUDY, MINIATURIZED TANKS ON SCALED TERRAIN

PERFORMING ORGANIZATION
NAVAL TRAINING DEVICE CE NTER
ORLANDO FLA. 32813

RESPONSIBLE GOVT ORGANIZATION
NAVAL TRAINING DEVICE CE NTER
ORLANDO FLA. 32813

PRINCIPAL INVESTIGATOR
PHILLIPS, E N

ASSOCIATE INVESTIGATOR

TELEPHONE NUMBER
305-841-5611, X2480

CONTRACT/GRANT NUMBER

PERFORMANCE METHOD
IN-HOUSE

CONTRACT/GRANT AMOUNT
$ 0

DATE OF SUMMARY	START DATE	ESTIMATED COMPLETION DATE
15 APR 69	JAN 68	APR 69

KIND OF SUMMARY	SUMMARY SECURITY	WORK SECURITY
TERMINATED	UNCLASSIFIED	UNCLASSIFIED

SCIENTIFIC AND TECHNOLOGICAL AREAS
005700 ELECTRONICS AND ELECTRICAL ENGINEERING

PROGRAM ELEMENT:	PROJECT NO:	TASK NUMBER:
62703N	F41522	XF41522013

KEYWORDS: (U) TERRAIN MODELS ;(U) TANKS (COMBAT VEHICLES) ;(U) SCALE (RATIO) ;(U) RADIO CONTROL

DESCRIPTORS: (U) DEFORMATION ;(U) MANUFACTURING ;(U) COMMUNICATION AND RADIO SYSTEMS ;(U) REMOTE CONTROL ;(U) SIMULATION ;(U) *TANKS(COMBAT VEHICLES) ;(U) TERRAIN ;(U) *WAR GAMES

IDENTIFIERS: (U) MINIATURIZATION ;

OBJECTIVE: (U) A FLEXIBLE SCALED TERRAIN WILL BE BUILT UP. ON ITS SURFACE ARE A NUMBER OF PARALLEL CONDUCTING STRIPES WHICH WILL FEED MINIATURIZED TANK FEED ROLLERS. THIS SCALED TERRAIN MUST BE CAPABLE OF MILD DEFORMATION TO SIMULATE ALTITUDE.

APPROACH: (U) A TECHNIQUE OF IMPRINTING CONDUCTING STRIPES ON A

FELT-LIKE FABRIC BASE WILL BE APPLIED. ADDITIONAL ALLIED TECHNIQUES WILL ALSO BE INVESTIGATED PROBLEMS INVOLVED IN JOINING FABRICATED SEGMENTS INTO AN OVERALL TERRAIN WILL BE INVESTIGATED.

RESOURCE ESTIMATED (FUNDS IN THOUSANDS) CFY 0
CFY-1 0

CONTRACTOR ACCESS: YES ACCESSION NUMBER: DN821010

PROCESSING DATE: 20 DEC 88

APPENDIX C:

THE MECHANIZATION OF WORK

Established 1845 **SCIENTIFIC AMERICAN** September 1982 Volume 247 Number 3

The Mechanization of Work

Introducing an issue on the continuing Industrial Revolution two centuries after it began. In the U.S. it has now displaced two-thirds of the labor force from the production of goods

by Eli Ginzberg

The easing of human labor by technology, a process that began in prehistory, is entering a new stage. The acceleration in the pace of technological innovation inaugurated by the Industrial Revolution has until recently resulted mainly in the displacement of human muscle power from the tasks of production. The current revolution in computer technology is causing an equally momentous social change: the expansion of information gathering and information processing as computers extend the reach of the human brain. This issue of *Scientific American* is devoted to the latest stage of the historic process that has led from the most elementary force-transmitting machines to the most advanced information-handling ones.

The transformation of the U.S. labor force in the country's brief history tracks the progressive mechanization of work that attended the evolution of the agrarian republic into an industrial world power. In 1820 more than 70 percent of the labor force worked on the farm. By 1900 fewer than 40 percent were engaged in agriculture. Half a century ago, when the capitalist societies were sliding into the Great Depression, more than half of the U.S. labor force had shifted from the production of goods to the provision of services. It was then, as large-scale unemployment destabilized those societies, that national policy began to look at employment as much from concern to ensure the consumption of goods as from concern to secure their production.

Today employment in the services in the U.S. is approaching the same 70 percent that were bound to the soil a century and a half ago. Only 32 percent of the labor force are still engaged in the production of goods (mostly in manufacturing), and a mere 3 percent are employed in agriculture.

Although this transformation has been brought about largely by mechanization, it has been accompanied by social trends so pervasive that they must be included among the causes of the transformation as well as among its effects. For example, although women had begun to enter the labor force from the beginning of the Industrial Revolution, by 1980 they had come to make up 43 percent of it [see "The Mechanization of Women's Work," by Joan Wallach Scott, page 166]. The age of entry into the labor force has risen, reflecting the desire of Americans for more education and the higher level of training required by jobs in the increasingly sophisticated economy as well as the release of human labor from the tasks of production. In 1940 the median number of years of school completed by the younger members of the population was 10.3; in 1980 it was 12.9.

A disquieting feature of these dynamic internal shifts in the labor force has been the persistence of high levels of unemployment among its less educated members. Such unemployment raises the question of how any society can function effectively over the long run without bringing all its adult members into its economic life, able not only to work but also to buy [see "The Distribution of Work and Income," by Wassily W. Leontief, page 188].

The five articles that follow take up the technologies of mechanization in five areas: agriculture, mining, design and manufacturing, commerce and office work. This introductory article will of necessity deal with a limited number of themes: how the mechanization of work has been treated by economists, what its effect has been on the U.S. economy over the past few decades and what its future effect is likely to be. Particular attention will be paid to the impact of mechanization on the shifting structure and character of the labor force and on the evolution of the work environment.

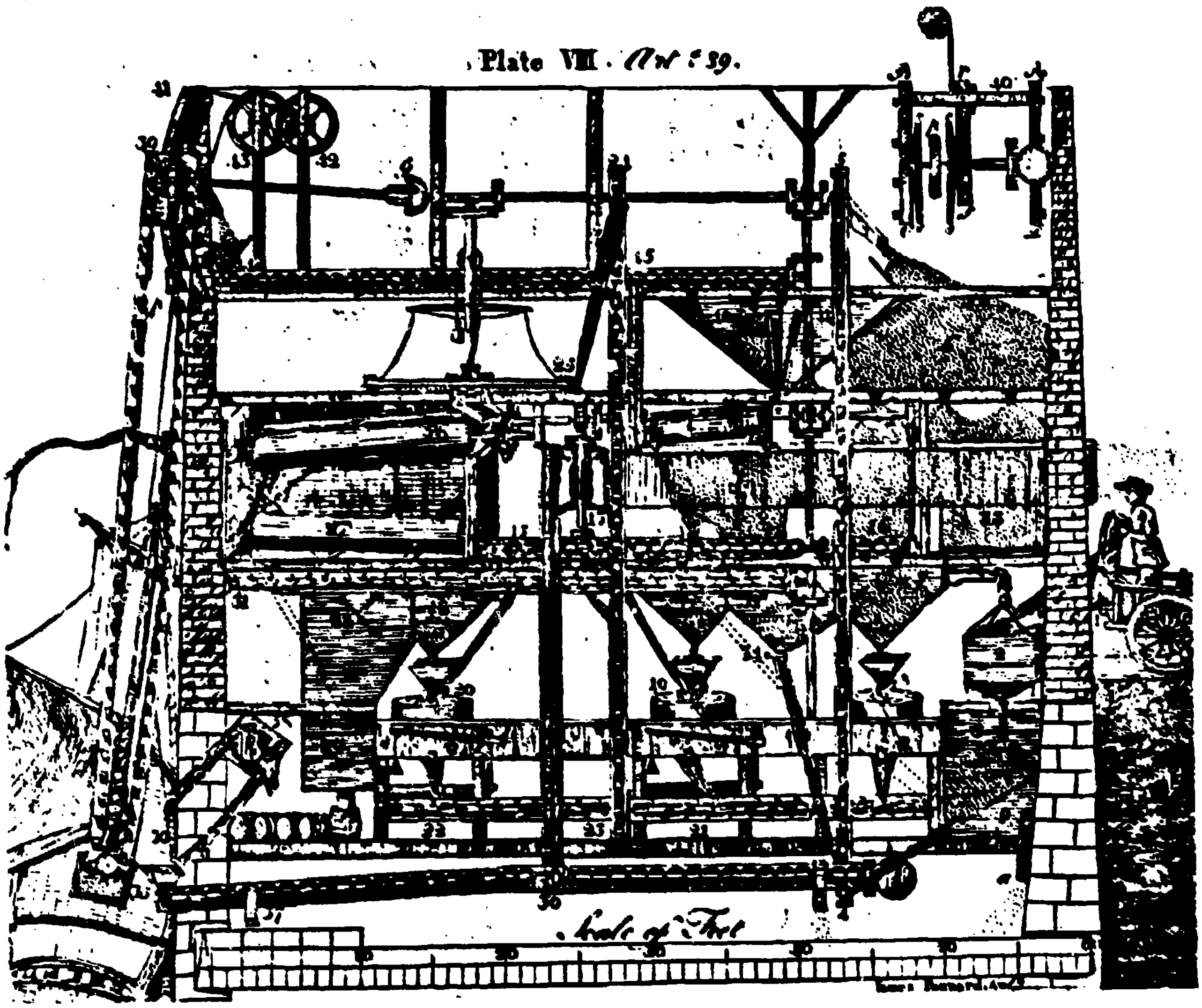
Adam Smith, in *An Inquiry into the Nature and Causes of the Wealth of Nations*, published in 1776, pointed to a basic dilemma: efficiency in the generation of wealth is enhanced by the division of labor, and yet specialization that involves nothing more than routine, repetitive tasks diminishes the worker by depriving him of intellectual challenge and decision-making responsibility. Smith, preoccupied with issues of moral philosophy, expressed his concern that many workers, in a desperate effort to improve their economic circumstances, would drive themselves so hard that it would affect their health and even shorten their lives. Smith's book was written before the commercial success of James Watt's steam engine, and so Smith never had to confront the full force of modern industrialization. He nonetheless appreciated the close links between the work men do and the quality of their lives.

David Ricardo, who began his study

WORKERS AT A STEEL MILL in Pittsburgh were recorded by the noted documentary photographer and social reformer Lewis W. Hine in about 1910. Hine's revealing images of the adverse conditions of industrial labor in the early decades of this century were instrumental in the enactment of laws governing occupational safety and the employment of children. Much of the work being done by human muscle in this scene is now done by machine. The photograph, which is from the archives of the National Child Labor Committee, is now part of the Edward L. Bafford Photography Collection of the University of Maryland Baltimore County.

of political economy after reading *The Wealth of Nations* in 1799, went on to establish the classical, or free-market, school of economics. In spite of his almost exclusive emphasis on the competitive marketplace, he cautioned that increased reliance on mechanization might not turn out to be an unqualified blessing. He could see that under certain conditions workers displaced by machines might not be able to get new jobs. What was good for the employer, he concluded, might be bad for the worker.

Karl Marx devoted some of the most telling chapters in *Das Kapital* to describing the adverse effects of mechanization on the minds and bodies of working men, women and children in mid-19th-century Britain. (Because women and children received lower wages they were then replacing men in many branches of indust y, from coal mines to textile mills.) According to Marx, the combination of machines,



MECHANICAL FLOUR MILL patented by Oliver Evans of Philadelphia in 1790 has been described as the world's first automatic factory and the forerunner of the modern continuous production line. This schematic diagram is from *The Young Mill-Wright and Miller's Guide*, published by Evans in 1795. The mill could be supplied with grain from either a boat or a wagon. In the latter case the wagoner dumped the grain into a spout (*1*), from which it flowed into a scale (*2*) for weighing before falling into a small garner, or granary (*3*). The grain was then led to a vertical bucket conveyor (*4, 5*), which raised it to the top floor. There a crane spout could deposit it in the main storage garner (*6*), from which it could be directed into a hanging garner (*7*) that in turn fed a millstone (*8*) for rubbing, or shelling, the grain before it was ground. The rubbed grain ran by a special channel (*broken lines*) back to the first garner, where the chaff was blown through a screen into an adjacent room (*9*). The grain was again elevated to the top floor, and the crane spout was turned this time over a pair of screen hoppers (*10, 11*), which fed a rolling screen (*12*). From there the grain descended through a current of wind made by a fan (*13*). The clean, heavy grain fell through a funnel (*14*) into a horizontal screw conveyor (*15, 16*), which distributed it uniformly to the three hanging garners (*7, 17, 18*), maintaining a constant flow of grain to the millstones (*8, 19, 20*). The ground meal was moved by another screw conveyor (*21, 22*) to a second bucket conveyor (*23, 24*), which emptied it into a rotary structure called the hopper boy (*25*); this device in turn spread the meal to cool it, sweeping it gradually through holes in the floor into a room called the bolting chest, where it was sifted by a set of rotating cloth sleeves called bolting reels (*26, 27*). The superfine flour collected in a packing chest (*28*) and was led out through a spout (*29*) to fill the barrels, which could then be loaded on the boat (*30*). The coarsely ground material was removed by another screw conveyor (*31*) to a garner (*32*), which also collected the light grain blown by the fan; the chaff was driven farther by the wind and fell into a separate chaff room (*33*). The coarse material was recycled by passing it through a gate (*34*) to the bottom of the first elevator. The grain supplied by boat could be unloaded from the hold by several methods: by an articulated screw conveyor (*35, 36, 37*), by a short bucket conveyor with a fixed upper pulley (*38*) or by a long external elevator (*39*) leading to the top floor. The pulley of the external elevator was designed to rise and fall in a pair of curved slots (*41*); the mechanism for hoisting the elevator clear of the boat (*42, 43*) is shown in another view (*40*). A screw conveyor on the top floor (*44, 45*) moved the grain into the mill. Evans finished the first model of his mill in 1783, and two years later a full-scale operating version was built at Red Clay Creek near Wilmington, Del. He promoted his invention vigorously, maintaining that his improved milling machinery "lessens the expense of attendance by at least one half."

private property and competition would soon result in the self-destruction of the capitalist system. The end would come, he said, when newer and more powerful machines would drive such a large proportion of the labor force out of work that producers would no longer have enough consumers to buy the goods their machines were turning out. With the advantage of hindsight one can now see that Marx was better as a critic than as a prophet. He correctly perceived that the Industrial Revolution was harming millions of working people, but he did not allow for the substantial gains in well-being they and the generations of workers after them would enjoy because of the increased productivity resulting from mechanization.

Thorstein Veblen made technology the basis for his own penetrating analysis of modern capitalism, from his first major work, *The Theory of the Leisure Class*, published in 1899, to his last, *Absentee Ownership and Business Enterprise in Recent Times*, published in 1923. Veblen consistently maintained that the way work is organized to suit the requirements of machines determines how men think, act and dream.

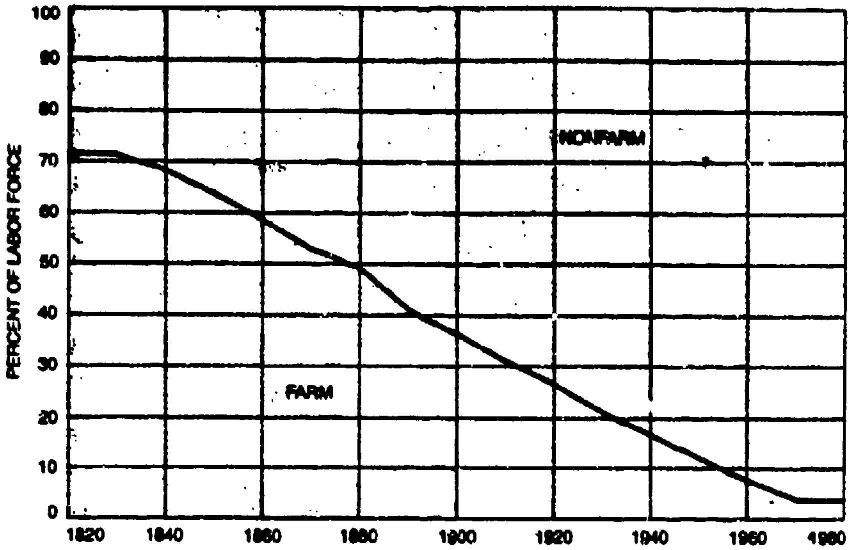
In general, however, most economists—free-market, Marxist or otherwise—have failed to give technology its due. The classical theorists and their successors have built their systems and their reputations by explicating with ever greater subtlety how demand, supply and price interact in competitive markets to establish or reestablish equilibrium. To pursue this static line of inquiry they have had to ignore the influence of such dynamic factors as changes in demography, technology and taste. Moreover, because they have a limited view of efficiency they search for the margin where it pays an employer to install machines to replace workers but seldom look into such factors as the quality of the workplace and the home, both of which have come increasingly under the influence of machines.

The shortcomings in the economists' approach to the mechanization of work can help to explain many of the errors in perception and action that have characterized the U.S. economy in the period since World War II. A better understanding of the complex relations between mechanization and the economic process can be gained by reviewing some of the more important of these misperceptions and the inadequate policies they have engendered.

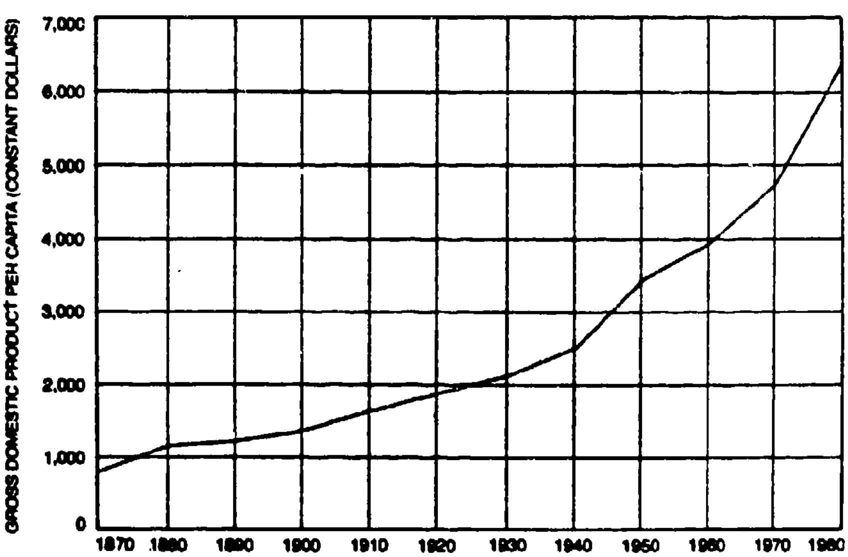
In 1947 the U.S. instituted the Marshall Plan. If the countries of Western Europe—both the victors and the vanquished—could agree to work together, the U.S. promised to provide them with the capital needed to speed the rebuilding of their devastated economies. Within a few years the economies of Western Europe had turned around and were growing rapidly.

The success of the Marshall Plan had much to do with the inauguration of smaller-scale programs of economic assistance designed to accelerate the industrialization of the less developed countries. They too became the beneficiaries of American capital exports. Here, however, the record of accomplishment turned out to be much less impressive. Little of the so-called economic assistance went to economic development. Instead American capital exports often went in the form of arms and American dollars added to the personal wealth of those in power. Only in retrospect has it been possible to understand the reasons for the difference in outcomes. In Europe the war had destroyed factories, power plants, railroads and other facilities, but the knowledge required to run an industrial economy had remained intact. This knowledge, accumulated over a century or more, was drawn on to make good use of the new machines as soon as they were installed. In most of the Third World there was no such pool of experience, and as a result many of the imported machines were installed only after considerable delay; frequently they were operated far below capacity, and they were poorly maintained.

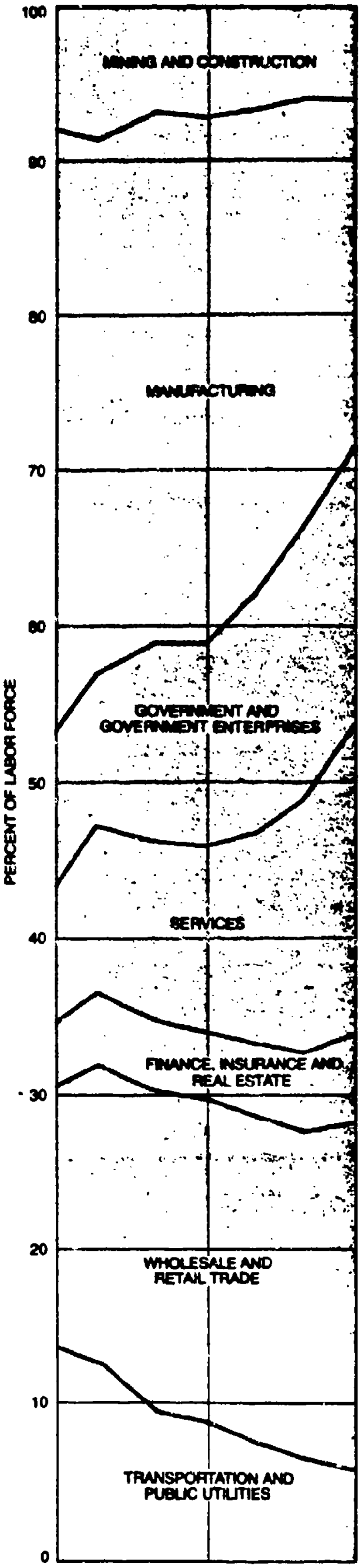
A second example of failure to bring



HISTORIC DECLINE in the fraction of the U.S. labor force employed in agriculture reflects the high degree of mechanization achieved on the farm in the past century and a half. In recent years agriculture in the U.S. has actually become more mechanized than manufacturing.



GROSS DOMESTIC PRODUCT of the U.S. has continued to rise at an approximately constant rate, when measured on a per capita basis. Nevertheless, there is considerable concern about the recent sharp decline in productivity, measured as a function of units of labor input.



mechanization into the center of economic policy is provided by the U.S. automobile industry. Until its recent troubles that industry was looked on as the bellwether of the American economy, proof that the U.S. was the technological leader among the developed nations. Year after year the industry's sales and profits were large, and although working conditions in the assembly plants were often unpleasant and arduous, the work force was well paid and received excellent benefits. The misperception of what was happening in Detroit resulted from a widespread failure to recognize that the industry's continuing high profitability rested primarily on styling, advertising and marketing, not on advances in engineering and in manufacturing technology.

In 1962 Congress, convinced that mechanization was resulting in the disemployment of many skilled workers who would never be reabsorbed into the labor force unless they could be helped to acquire new skills, passed the Manpower Development and Training Act. That act, together with its successor legislation, the Comprehensive Employment and Training Act (CETA), passed in 1973, led to the expenditure of more than $80 billion up to the beginning of the Reagan Administration, mostly to help the poor and the near-poor. It is doubtful, however, that even 1 percent of the outlay was directed to the retraining and reemployment of workers who had lost their jobs through mechanization, because such workers could until recently make their own way into new jobs.

The most recent example of confusion about the mechanization of work arises from national economic policies ostensibly directed to "reindustrialization" (for example tax cuts for accelerated depreciation of plant and equipment, a measure expected to start a new boom in investment). The U.S. is urged to pursue other policies, public and private, that will putatively enable it to regain its eroding leadership in the manufacture of a wide range of industrial and consumer products, from steel to automobiles and television sets. Much is made of the superiority of Japanese management and the dangerous decline in the productivity of U.S. industry. However the issue is formulated, the core elements are the same: the leadership of the U.S. in technology has slipped, and there is a serious dysfunction in the attitudes, behavior and output of American workers.

Actually the available statistics suggest that on a per capita basis the U.S. is close to its long-term trend in gross domestic product (G.D.P.): the output of all domestically produced goods and services. The unease centers on the recent sharp decline in productivity (measured as the ratio of total production to units of labor input). Any interpretation, however, is plagued by complications: the reported hours of work overstate the actual hours worked, exaggerating the measured declines in productivity; the U.S. economy has been shifting rapidly from goods to services, a shift that inadequately reflects the increases in output; the statistics also fail to adequately reflect changes in quality, investments in the public sector and what is happening outside the market, notably in the "underground economy" and in the household. If one were to understand and take proper account of these developments, the performance of the U.S. economy would probably be better, and possibly much better, than the current statistics suggest. Americans may well be unduly worried over a phenomenon that reveals more about the limitations of economic analysis and statistical reporting than about the economy itself.

The fact remains that mechanization has continued to play a leading role in the transformation of the U.S. economy and other developed economies in the past half century, as it did in the preceding century and a half. New and better machines have contributed to reducing the average weekly hours of work in manufacturing from 44 in 1930 to fewer than 42 today. At the same time mechanization has contributed to major gains in the rewards for work: the average pay in manufacturing has risen from $1.60 per hour then to $3 now (in constant 1967 dollars). This excludes fringe benefits, which have grown on the average to about 35 percent of base pay. Moreover, some economists have come to appreciate that the key to economic progress lies less with the accumulation of physical capital and more with the broadening and deepening of human capital, since it is human talent alone that is capable of inventing, adapting and maintaining machines.

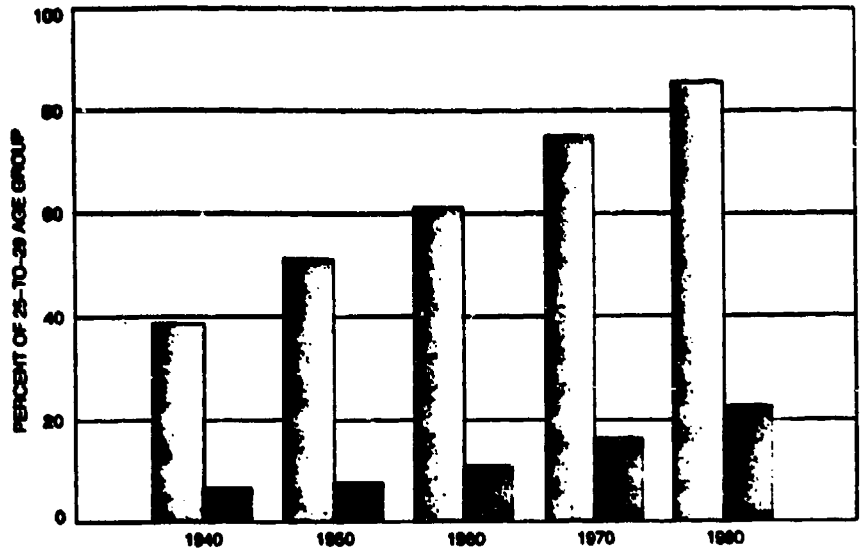
Part of the problem is that the majority of economists, with their strong bias in favor of the competitive market, have paid inadequate attention to the contribution of the public sector to accelerating the growth of human capital. Public support has taken different forms: the

GROWTH OF THE SERVICE SECTOR of the U.S. economy is represented in color on this graph for the period 1920–80. The subcategories indicated cover all wage and salary workers (including full- and part-time workers) employed in nonagricultural establishments. Included are workers in the nonagricultural goods-producing sectors (manufacturing, mining and construction) and those in the service sector, defined in the broadest sense to encompass all enterprises not engaged in the production of goods. (The subcategory "Services" is narrowly defined to designate those workers who provide services primarily to consumers.) Excluded (besides farm workers) are proprietors, self-employed people, domestic servants and unpaid family workers.

"G.I. Bill of Rights" of 1944, the expansion of public higher education, Federal financing of research and development, and the large-scale proliferation of specialized training programs created as by-products of efforts to build up the country's military strength and to develop nuclear power, aircraft, computers, spacecraft, communications and other large-scale technologies.

In the three decades between the election of President Eisenhower and the election of President Reagan both per capita disposable income and family income, expressed in constant dollars, almost doubled. Trade unions have become a prominent feature of the industrial landscape (although their membership as a fraction of the total work force has declined since 1955), and a professional, college-trained cadre of managers has taken command of most U.S. corporations. It would be surprising indeed if, mechanization aside, the foregoing changes had not left their mark on how workers behave both on the job and off it.

Other factors must also be taken into account: the repeated involvement of the country in foreign wars, the growing threat of nuclear war, rapid changes in basic values and behavior involving aspects of life from sex to religion, increasing skepticism about and challenges to authority and legitimacy. Only those economists who believe everything in life is determined by the calculus of the marketplace would attempt to explain the difficulties in which the U.S. economy finds itself in 1982 as resulting from a collapse of the work ethic. The Luddites looked on the machine as the villain; the supply-siders blame the worker.



EDUCATIONAL ATTAINMENT of the U.S. population has risen markedly in the past few decades. The colored bars indicate those in the 25-to-29 age group who have finished four years of high school; the gray bars correspond to those who have been graduated from college. Between 1940 and 1980 the median number of school years completed rose from 10.3 to 12.9.

The second of the three themes I mentioned at the outset is the extent to which mechanization has helped to change the U.S. economy since World War II. Of the 41.6 million people employed in 1940 (excluding the self-employed and domestic servants) 54 percent were engaged in the production of goods: in agriculture, mining, construction and manufacturing. Mechanization had earlier made steady advances in the grain-producing states of the Middle West, but it had only a minor place in the cotton culture of the Southeast. The South, in the view of President Roosevelt, was the nation's No. 1 economic problem. It conformed to the Marxian view that surplus labor would be concentrated on the farm, living at the margin of subsistence and awaiting an opportunity to relocate to urban centers when employers needed additional workers. As late as 1940 four out of five black citizens were still living in the South, the majority of them on farms they sharecropped.

World War II was the continental divide. Many blacks went into the armed services; others moved to the North and West, where employers faced growing labor shortages; still others moved into Southern cities, many of which were being transformed by the infusion of military dollars. Other farming areas also sustained a large-scale exodus of surplus labor, setting the stage for the accelerated mechanization of agriculture. Paradoxical as it may seem, agriculture is now considerably more mechanized than manufacturing.

In the same four decades mechanization made rapid advances in bituminous coal mining as a result of two factors: the development of strip mining in the West and the decision of the United Mine Workers' Union, led by John L. Lewis, to favor higher wages over more jobs. In spite of the widespread belief that strong unions have inhibited mechanization in the construction industry, the evidence from the mechanization of excavation to the prefabrication of structures points to major advances in the application of sophisticated technologies. Although some construction unions have been strong enough to delay the introduction of new machines or to prevent the new machines from operating at full capacity, these delaying tactics have in certain instances stimulated the growth of nonunionized industry, where contractors were able to mechanize without interference.

At the height of the war boom the goods-producing sectors of the U.S. economy accounted for 69 percent of the employed labor force. In 1980 they accounted for 32 percent. The most striking shift in the goods-producing sectors was the decrease in the number, both absolute and relative, of agricultural workers. The second most prominent shift was the relative decline in manufacturing, where employment increased from 34 percent of all nonagricultural jobs in 1940 to 41 percent in 1943 but declined to 22 percent at present.

The decreasing employment in the goods-producing sectors of the economy was first matched and then exceeded by the increasing employment in the service sector. Between 1940 and 1980 employment in service occupations grew from 46 percent of total employment to 68 percent. Of all new jobs added to the economy from 1969 to 1976, 90 percent were in services.

What are the reasons for this shift? The answers differ depending on who is asked. Some economists deny that a significant shift has occurred; at most they will agree that there has been a slow, steady growth of service-sector jobs. Some acknowledge that a shift has occurred, but they ascribe it primarily to the explosive growth in health, education and related services. They expect that the growth will level off and even decline now that the birthrate is down and the Reagan Administration is pressing to reduce the level of Government outlays. Others, including our own group at Columbia University, are convinced that there has been a tilt of demand toward more consumer services and that, even more important, changes have been made in the way goods are produced, calling for a vast expansion in "producer services." Thomas M. Stanback, Jr., and his colleagues at Columbia, in their recent book *Services/The New Economy*, note that the value added of producer services alone—financial, legal, accounting, marketing, management consulting and communications—

equals the value added of all manufacturing output.

A look at the changes in the occupational structure further illuminates the causes and consequences of the shifts identified here. Somewhat simplistic comparisons can be made among white-collar workers, blue-collar workers and service-sector workers (narrowly defined as those who provide services primarily to consumers). In 1940 the proportions employed in these kinds of occupation were respectively 31 percent, 57 percent and 12 percent; in 1980 they were 54 percent, 34 percent and 12 percent. Bigger and better machines on the farm, in the mines, in the factory and at construction sites call for fewer operatives. In modern oil refineries, chemical plants and steel-fabricating mills there is a great deal of machinery but there are few workers, and many of the workers are engaged in white-collar jobs. The General Electric Company, which manufactures tens of thousands of different items from turbines to electric-light bulbs, has no more than 40 percent of its employees directly engaged in production; the rest work in what can best be classified as in-house producer services from accounting to marketing.

If one looks at the qualitative changes that are suggested by the shift from blue-collar to white-collar employment, one finds a truly impressive growth in the two groupings in the standard categories of the Bureau of Labor Statistics that have the highest status and incomes: professional, scientific and technical workers, and managerial and administrative workers. Between 1940 and 1980 the former group increased from 7.5 to 16 percent of the employed labor force, and the latter group declined from 20 to 13 percent. The last two figures conceal a major qualitative transformation, since they lump the owners and managers of small enterprises, whose numbers declined, and corporate and other high-level administrators, whose numbers rose.

Confirmation of the radical changes in the occupational structure can be found in the striking rise in the educational achievements of the younger members of the work force: those between 25 and 29 years of age. One need not hold the philistine view of many human-capital theorists that educational preparation is determined solely by the estimates people make of their career and income prospects to see that the two factors are definitely correlated. The large increase in the proportion of those in the 25-to-29 age group who have either an undergraduate degree or a higher degree is striking: from one in 16 in 1940 to almost one in four in 1980.

There is a bias among economists going back to Adam Smith that only work resulting in a physical output is productive and that services, which are by their nature ephemeral, are unproductive. Smith, reacting to the excessive number of family retainers among the rich, misled himself and his followers about the nature of services. Economists finally realized, however, that an artist who gives pleasure to thousands or a surgeon who restores the health of hundreds must be considered productive. Nevertheless, the followers of Smith have been preoccupied with refining the manufacturing model. With few exceptions the output of services has been downgraded or ignored.

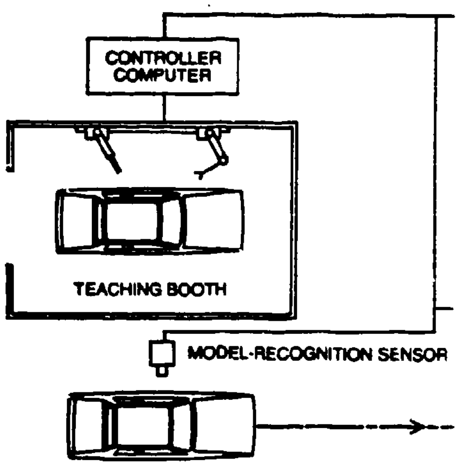
This bias against service occupations was reinforced by a widespread belief that mechanization, the key to productivity and growth, has little or no role to play in the production of services. In fact, some contemporary economists have separated out the heavy, capital-intensive services—transportation, communications and electric-power utilities—and treated them as either part of or closely related to conventional manufacturing.

A further bias has been at work. Many services are anchored in the public sector rather than the private sector; the leading examples are education, health and such basic functions as police protection, fire protection and sanitation. Economic theory based on the competitive marketplace has little to contribute to an understanding of such public services. Handicapped by tradition, economists have been slow to understand the shift of modern economies toward services and in particular toward services in the public sector, toward producer services and toward mechanization in large service enterprises.

Most economists assumed that service companies would inevitably continue to be small, since service providers had to interact personally with consumers, as in the case of a restaurant, a dry-cleaning establishment, a physician or an accountant. The model of the small local consumer-service company, however, clearly does not fit the fast-food chains, the international banks with branches in 100 or more cities, the worldwide hotel chains, the national retailing chains and many other national and international service enterprises that have been able to mechanize many of their critical functions, from finance to personnel management.

As I have noted, the period since World War II has also been marked by a steady advance in the educational preparation and skill level of the work force, as exemplified by the increase in the number of white-collar workers and of professional, scientific and technical workers. The question remains of whether it is more difficult in the service sector than it is in the manufacturing sector to move from a less desirable job to a more desirable one. Stanback believes this has been the case. He points to the steelworker who began work in the yard and could move up many grades on the basis of seniority and on-the-job training. That is not the case, he observes, for the laboratory technician in a hospital or the paralegal worker in a law firm. In support of this argument, it has to be conceded that a college or professional degree is a prerequisite for competing for many of the best jobs in the service sector. On the other hand, talent appears to be as important as formal degrees in many occupations, such as advertising, design and sports. In my view the issue remains open.

These last considerations are a bridge to the third theme I mentioned at the outset: the effects of mechanization on the work environment. To the extent that any generalization is justified, one can maintain that the conventional attitude of the American worker toward machines has been different from that of



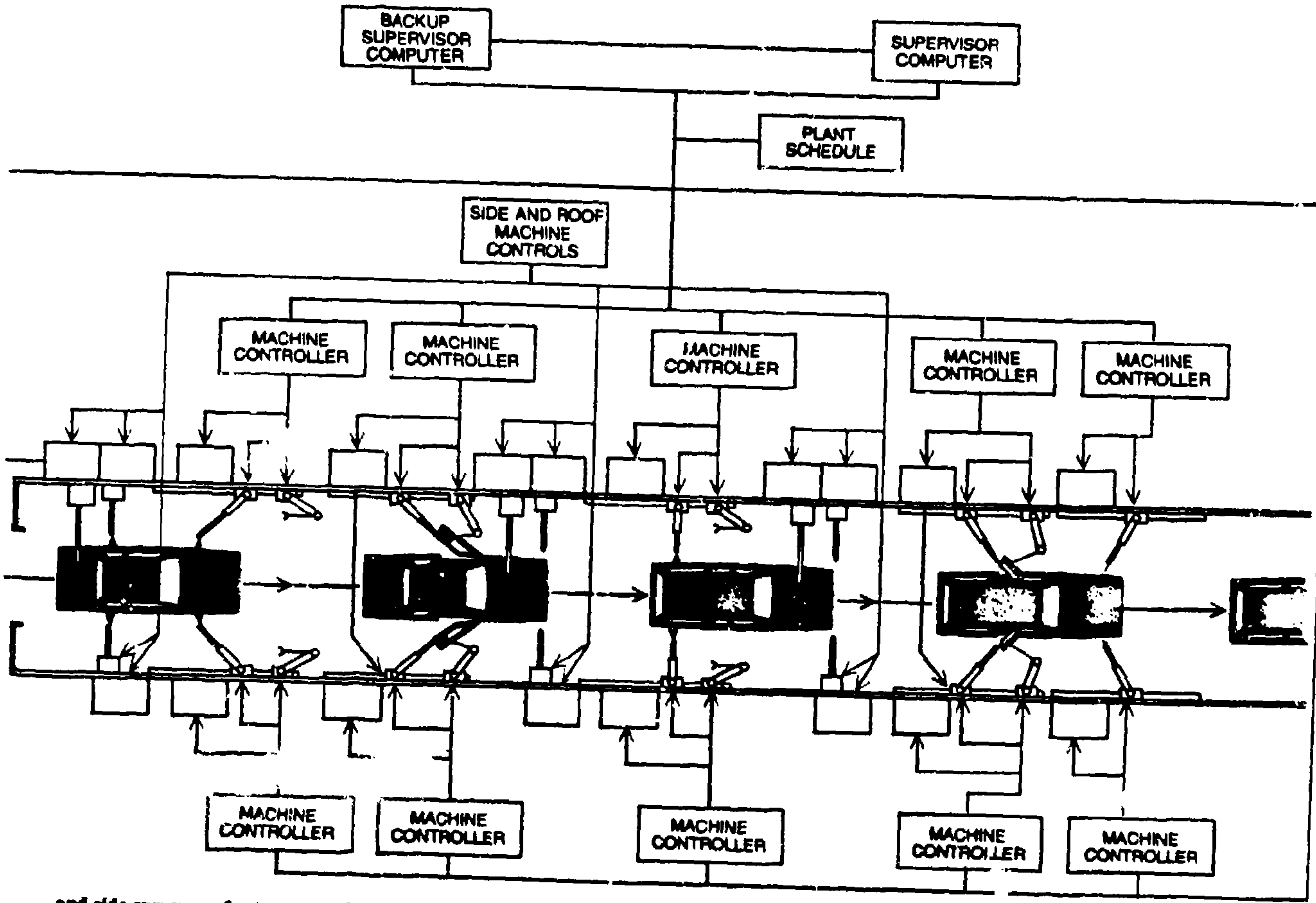
TOTAL MECHANIZATION of a new system for the spray painting of the bodies of cars and light trucks makes it possible to remove all human workers from a particularly onerous industrial task. The diagram shows the control hierarchy for the Numerically Controlled Paint System, which has been developed over the past seven years by the General Motors Corporation; the system has recently been installed at the GM assembly plant in Doraville, Ga. The present system consists of three pairs of automatic, fixed-stroke, roof

the European worker. For the most part, American workers have had a positive attitude toward technological improvements, seeing them as making their work less onerous and as providing an opportunity for wage increases through increased productivity and for the enhancement of their job security through improvement of their company's competitive position.

In European countries, with their smaller markets, the job-displacement potential of the new machines has been more prominent in the thinking and action of the workers. Technological unemployment was viewed as a serious threat by the principal unions in the German Weimar Republic of the 1920's, and even the economic revival of West Germany after World War II did not dispel this fear. In the early 1960's the largest of the West German unions, the metalworkers, were host to a week-long international conference on mechanization and the involuntary unemployment it could cause. The issue is once again high on the agenda of the West German trade unions, particularly because of the disturbingly high level of unemployment in that country.

Marx railed against the dehumanization of work in which the machine set the pace, a theme that was resurrected in succeeding generations by John Ruskin, Edward Bellamy and Emma Goldman and that was developed perhaps most imaginatively in Charlie Chaplin's motion picture *Modern Times*. One need not gloss over the physical and psychological strain of working on the assembly line to point out that at the peak probably no more than one in 15 or 20 American workers earned a livelihood by such work. Robert Schrank, whose *Ten Thousand Working Days* is the most perceptive account of the diversity of working environments in the contemporary U.S. economy, makes a strong opposing case. Instead of the machine's dominating the lives of the workers, he writes, the immediate work group learns to organize its activities to enlarge its scope of freedom to do the things its members most enjoy: swap stories, fool around, play games, gamble, keep the foreman off their back and otherwise interact with one another, investing little of themselves in carrying out their assignment.

Three decades ago, in the book *Occupational Choice*, my coauthors and I distinguished three returns from work: intrinsic (direct work satisfaction), extrinsic (wages and benefits) and concomitant (interpersonal relations on the job and in the work environment). Advocates of improving the quality of work life see major opportunities to enhance the intrinsic and concomitant returns that workers are able to get from



and side sprayers of a type already in wide use for such painting operations, five pairs of numerically co[illegible] paint machines (four pairs equipped with door-opening d[illegible] and an off-line teaching booth that houses another numerically controlled painter with its associated door opener. (The number of painting stations is expected to vary from plant to plant; one system currently being installed has 18 of the new machines.) The numerically controlled painter is a seven-axis device, hydraulically driven and servomechanically controlled. Its function is to paint all external body surfaces and various internal surfaces not covered by the roof and side sprayers. The machine's reach enables it to paint bodies of all sizes, ranging from subcompacts to full-size sedans, station wagons and pickup trucks. The painter's companion, the door opener, has two servo-controlled axes and one pneumatic axis. The supervisor computer tracks each car body through the painting booth and sends the correct path data to each machine controller at the proper time. A body-recognition system identifies each body as it enters the painting booth. The recorded information is sent to the supervisor computer and is checked against the plant schedule to determine the car's color and other options. In order to "teach" the painter a new routine a worker in the off-line teaching booth grasps a handle attached to the end of the teaching painter's arm and leads the spray guns through the appropriate paint paths, recording positions along the way and signaling "on" and "off" points. The resulting data are then stored in the system's computer.

their work. In my opinion they exaggerate. The scope for decision making by workers on the factory floor or in the large office is severely limited. An extreme division of labor results, as Smith perceived, in routine, repetitive tasks from which decision-making functions have been extracted.

Although American trade unions may have been too confrontational in their attitudes, their underlying conviction is that, beyond pressuring management to make the work environment safer, cleaner and more attractive, there is not much management can do to improve the intrinsic rewards from work. Accordingly unions have pressed and will continue to press for improvements in extrinsic rewards: job security, equity in selection for promotions, participation by the unions in discipline and discharge, better wages and fringe benefits, and more free time.

As my colleagues Ivar Berg, Marcia Freedman and Michael Freeman have documented in their book *Managers and Work Reform*, much of the agitation of the U.S. economy is a function of the expectations workers have about their jobs; there is a real danger that many are overeducated for the work to which they are assigned. Furthermore, much of the dissatisfaction of workers stems not from their limited scope to participate in decisions that affect their work but from their frustration with managers who fail to perform effectively.

Much of the preceding discussion of the workplace, worker motivation and the quality of work life has been in terms of the modern factory. Since the labor force is now overwhelmingly employed in the service sector, however, it seems desirable to call attention to a few future developments in the relation of mechanization to the work environment there.

Because of the critical importance of quality in the service sector the control of work and workers confronts management with a new and difficult challenge. Service-sector work has more dimensions and complexities than factory work, particularly considering the much higher proportion of professional, scientific and technical people employed in service industries. It is the hallmark of such personnel that their training has conditioned them to decide what work to do, how to do it and even when to do it. The members of a university faculty, although they are members of a department, a school and a larger institution, consider themselves as self-directed, autonomous individuals to whom the chairman, the dean and the president can address requests but not give orders. Increasingly this academic model is spreading to industry and government, to the research laboratories, to corporate staffs and to government agencies. There is growing tension between the traditional hierarchical structure of organizations and the implicit (and increasingly explicit) demands of professionals for greater autonomy in their work. How these demands will be reconciled with traditional modes of management remains to be seen, and the process of reconciliation may prove as difficult as it is important.

At the other end of the occupational scale it appears that the increase in the number of service-sector jobs has been correlated with the decrease in the fraction of the work force that is unionized. Many observers believe trade unions will be further weakened as the growth of the service sector continues. This may in fact happen, but several countervailing factors must be considered. Many service jobs pay low wages and provide limited benefits. More women, concentrated in low-paying service jobs, are becoming regularly attached to the work force. The computer revolution seems ready to make major inroads into the office, a development that holds a threat to the job security of many white-collar workers. The continuing erosion of the real earnings of workers by inflation makes these employees receptive to union organization. It is easy to write off the trade-union movement, particularly since it has had a conspicuous lack of success so far in restructuring itself to meet the challenges of a changing economy. Even if the unions finally succeed in making sizable gains in the service sector, they will face not only the conventional challenges of achieving higher wages and better fringe benefits for their members but also the challenge of contributing to a more stimulating workplace.

Veblen once explained the success of Germany in overtaking Britain as an industrial power in terms of the advantages of being second (or third). The latecomer did not have to carry the burden of obsolescent machinery or business practices. Many analysts in the U.S. in 1982 think Japan and the leading nations of the Third World have the same advantages Germany once had. The analogy is suggestive, but it is faulty. For some years various manufacturing activities have been moving to low-wage countries not only out of Western Europe and the U.S. but also out of Japan.

There is widespread concern about the periodic imbalances of U.S. trade in commodities with the rest of the world. In 1980 the deficit in such trade amounted to slightly more than $25 billion. That is not the whole story, however. Fees and royalties on direct U.S. investments abroad amounted to almost $6.7 billion, and net earnings on foreign investments, excluding these fees, came to $32.8 billion, resulting in a net surplus of more than $13 billion in goods and services (adjusting for the small net deficit in travel receipts). Goods and services do not lead totally independent existences, and as I have noted, services have come to play a much more important role in the production of goods. The challenge to the U.S. economy is not "reindustrialization" but rather "revitalization," in which mechanization has an important role to play with respect to both goods and services.

It is moot whether any new specific policies are required to speed revitalization beyond a recognition that the U.S. economy is moving ever more strongly into services and that the country's legislators and administrators should deal equitably between the different sectors in the creation and implementation of trade, tax and employment policies. The Reagan Administration, through the Office of the Special Representative for Trade Negotiations, has demonstrated a growing concern with international trade involving services. In the private sector a recently established consortium of major service companies is further evidence of attention and action.

A conclusion that government should not venture into the formulation of industrial policy does not imply that the state has no role to play in the strengthening of the industrial infrastructure. It is important to remember that government has played a major role in leading American industries: in agriculture, aeronautics, nuclear power, electronics, computers, communications, genetic engineering and other emerging technologies. If the present Administration has its way, the support of universities, the education and training of specialists and the underwriting of research and development will not be carried forward at an appropriate scale or with the adequate lead times. The machines that are invented, improved and put into operation throughout the economy depend on a steady accretion in the pool of knowledge and on the availability of enough technicians. If the country had to wait for the big corporations to train their own technical personnel from the ground up, it could wait a long time. Even if they wanted to do it, they could not. The ideologues may swoon over the beatitudes of the competitive market, which clearly has much to commend it, but the U.S. economy, for better or worse, is a pluralistic system in which government, nonprofit institutions and privately owned companies have complementary relations. No one of them, left to its own devices, can prosper in a technologically sophisticated world.

It would be a distortion to end this introduction to a series of articles on the mechanization of work without consideration of its problematical consequences. I shall therefore take up some of the consequences of mechanization for women and for the undereducated.

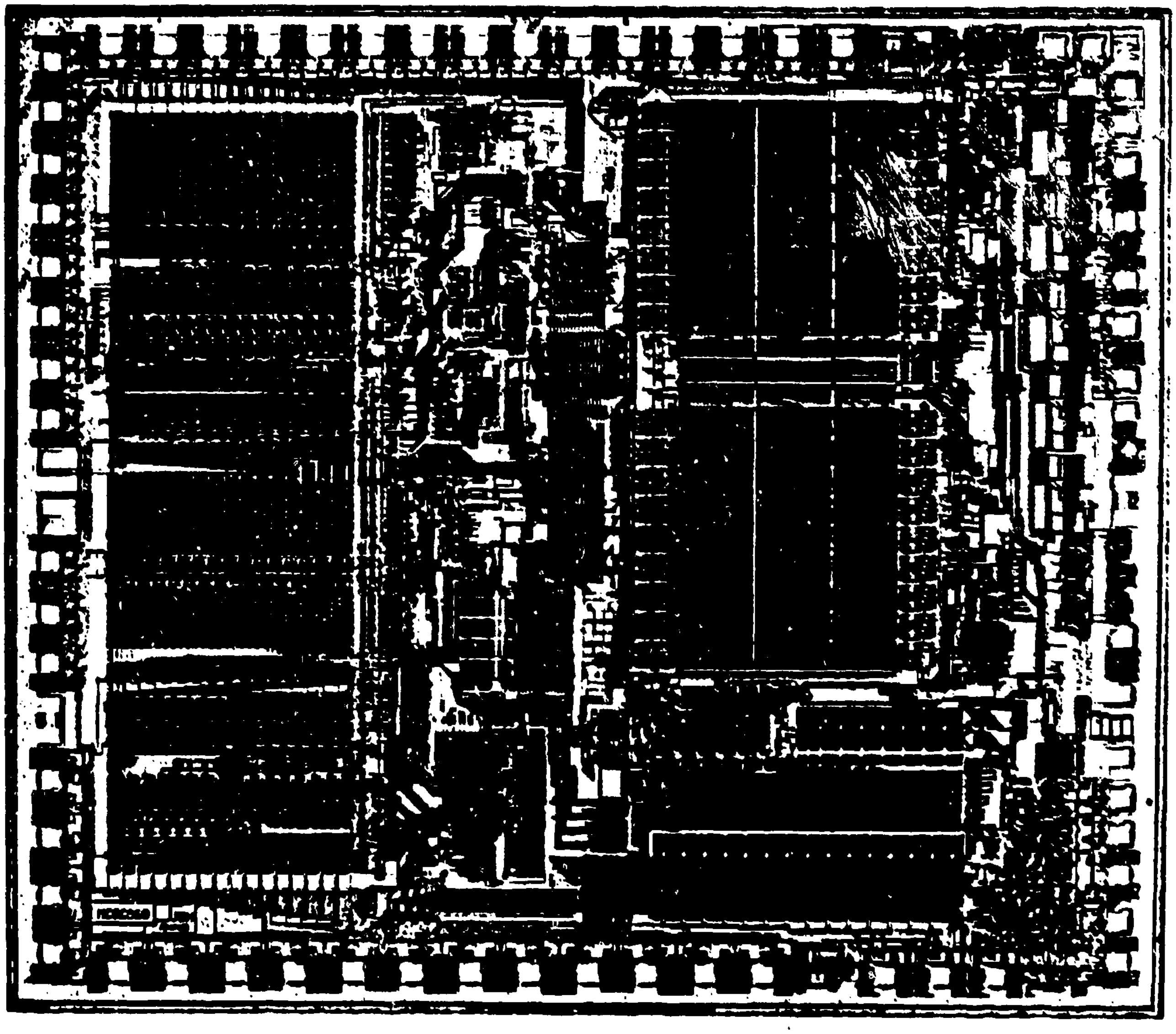
With respect to women, mechanization unquestionably paved the way for

many of them to escape the confines of the home as a result of laborsaving devices, which eased the chores of nousekeeping and, equally important, reduced the role of physical strength as a qualifying characteristic for many jobs. The positive role of mechanization in the liberation of women had little or no influence, however, on such untoward trends as the ominous rise in the number of households headed by women, the disturbingly large number of youngsters being brought up solely by their mothers and the large fraction of those families that live at or below the poverty level. These trends can be disregarded only by a society that is indifferent to human deprivation and unconcerned about its own future.

Before the introduction of sophisticated machinery as well as afterward all economies have faced difficulties in providing jobs for everyone who needs work. In spite of the good record of the U.S. economy with respect to the creation of jobs in recent decades Arthur F. Burns, the former chairman of the Board of Governors of the Federal Reserve System (and the current U.S. ambassador to West Germany), recommended in 1975, in the face of the continuing difficulties that many young people were having in finding and keeping jobs, that the Federal Government become "the employer of last resort" at wages 10 percent below the legal minimum wage. Some believe the shift of the economy toward services is currently making it more difficult for the undereducated to find a niche. An increasingly white-collar economy has no place for functional illiterates.

I have one concluding observation about the relation between mechanization and work. There is a widespread belief in the U.S. and Western Europe that young people have a smaller commitment to work and a career than their parents and grandparents had and that the source of the change lies in the collapse of the "work ethic." The question of why the work ethic collapsed is seldom raised, although sophisticated analysts suggest it is linked to economic affluence and the shift of concern from the family to the self.

I would suggest that the success of modern technology, which has put each of the superpowers in a position to destroy the other (and much of the rest of the world), presents a basic challenge, not only with respect to work but also with respect to all human values. It remains to be seen whether or not the potential of modern technology will turn out to be a blessing. Many young people are betting against such an outcome, and others are waiting before committing their modest stake



MICROPROCESSOR at the heart of the graphics computer shown in the painting on the cover crowds some 70,000 transistor sites onto a single chip of silicon measuring roughly a fourth of an inch on a side. The chip, designated the MC68000, is the first in a projected family of integrated 16-bit microprocessors developed by Motorola, Inc. The dark areas at upper right are the system's memory elements.

APPENDIX D:

GLOSSARY

GLOSSARY

Some Frequently Used Terms:

ICAM -	Integrated Computer-Aided Manufacturing (A USAF Program)
IDEF -	ICAM Definition Method (a modeling technique for analyzing systems)
$IDEF_0$ -	ICAM Definition Method, Version Zero (also called "Structured Analysis and Design Technique" and available commercially under that name from SofTech, Inc., the developer). A technique for modeling the functions (activities) of a system.
$IDEF_1$ -	The information modeling technique. It is used to create a model of the information required to accomplish the functions defined using $IDEF_0$.
$IDEF_2$ -	The dynamic modeling technique. Enables the analyst to create a graphic model of the system that relates system operation to time.
IDSS -	ICAM Decision Support System. This is a computer-based simulation capability for exercising the Dynamic model ($IDEF_2$), to permit evaluation of alternate design solution to improvement concepts, using quantitative measures of performance.
TECH MOD -	An Air Force Program to encourage aerospace manufacturers to develop and implement technological advances in their factory. Short for Technology Modernization.
MAN TECH -	Manufacturing Technology. An activity in itself, but also an Air Force Program for accomplishing the following four subprograms: o ICAM Program o TECH MOD Program o Generic Manufacturing technology projects (e.g., powdered metallurgy, advanced composites, advanced bonding techniques, etc.) o AFLC - Internal support to the Air Force Logistics Command.

ARCHITECTURE - A model of an entire operation, such as manufacturing. The architecture of manufacturing includes three models $IDEF_0$, $IDEF_1$, $IDEF_2$ - each corresponding to a different aspect of the system.

COST DRIVER - An operation which contributes disproportionately to the total cost of an enterprise. The ICAM Program tries to eliminate or reduce cost drivers through the application of the ICAM technology to the factory to develop new/improved/better-integrated capabilities which capitalize on automation.

APPENDIX E:

DESIGN AND MANUFACTURING: WHAT THEY MEAN TO FLEET READINESS

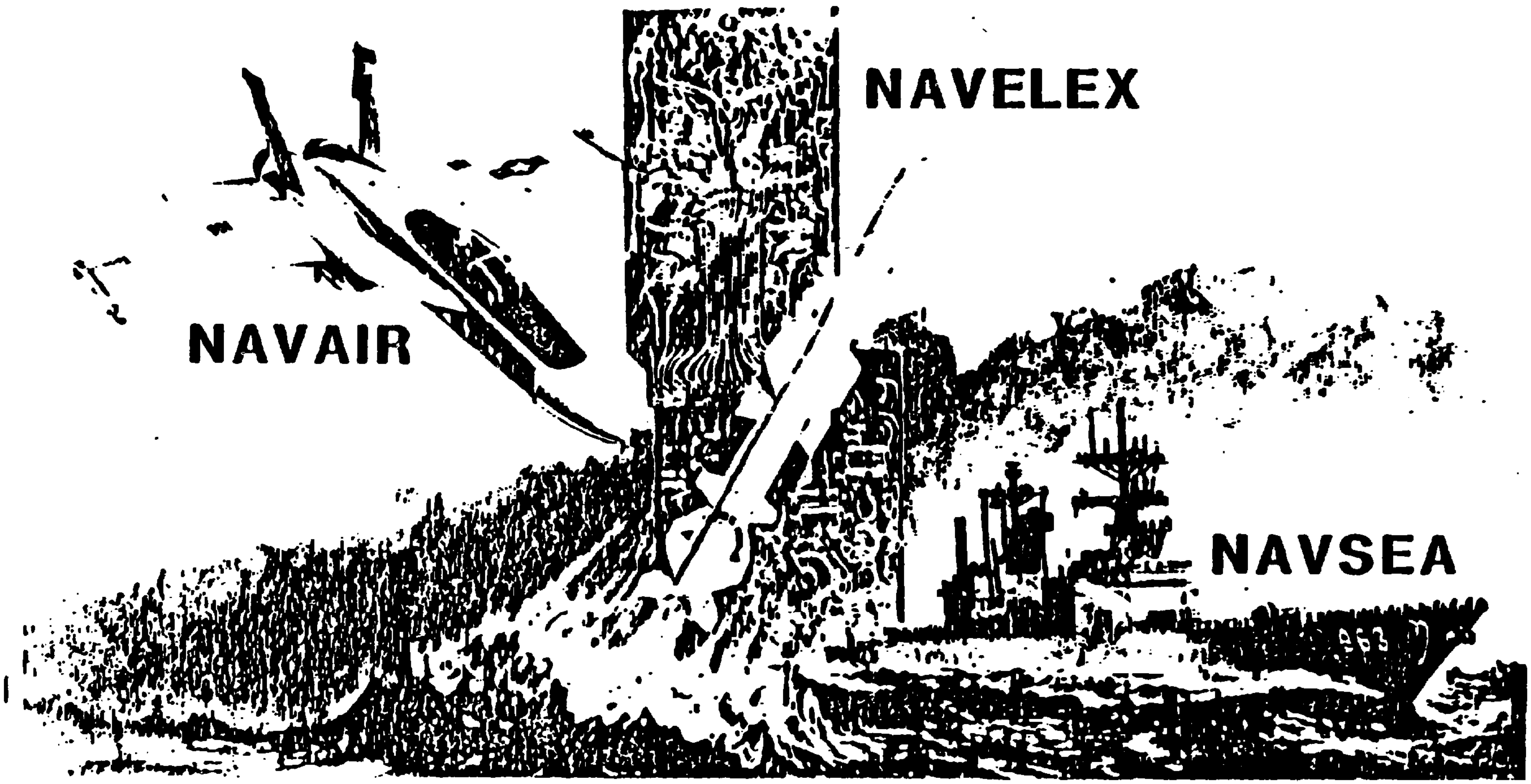
DESIGN AND MANUFACTURING

WHAT THEY MEAN TO FLEET READINESS

MANAGEMENT OF

A DISCIPLINED APPROACH TO FLEET READINESS

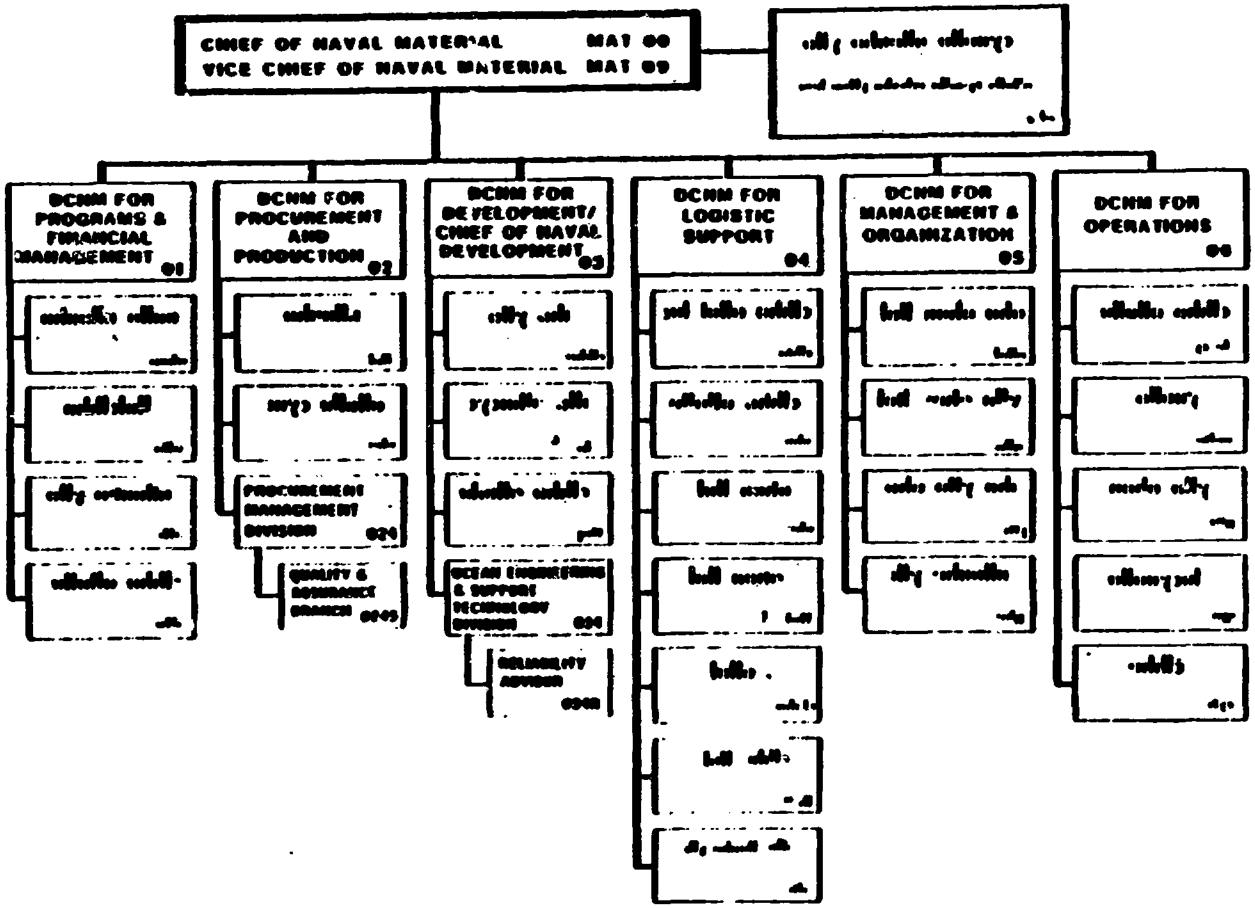
THE RELIABILITY MANDATE



NAVAL MATERIAL COMMAND — NAVMAT

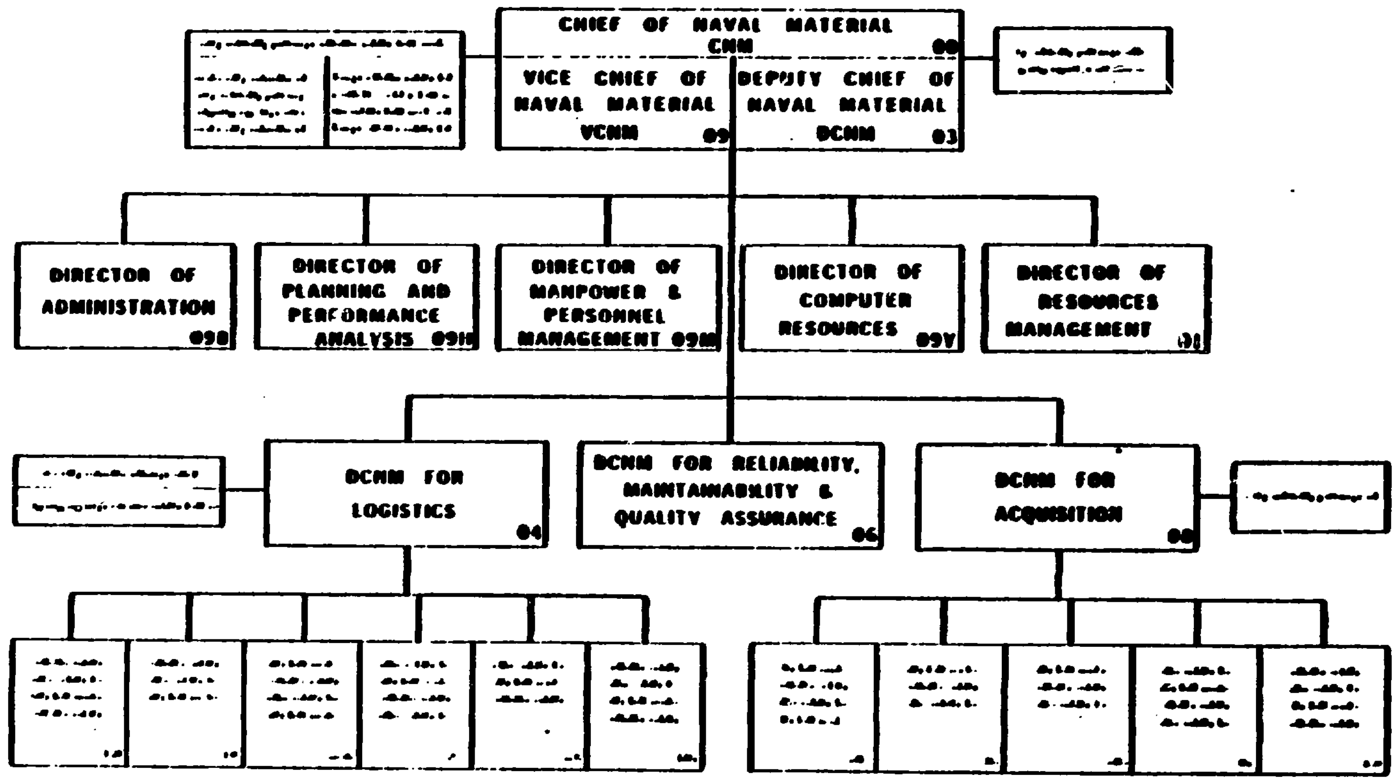
ORGANIZATIONAL STRATEGY
1973

HEADQUARTERS NAVAL MATERIAL COMMAND



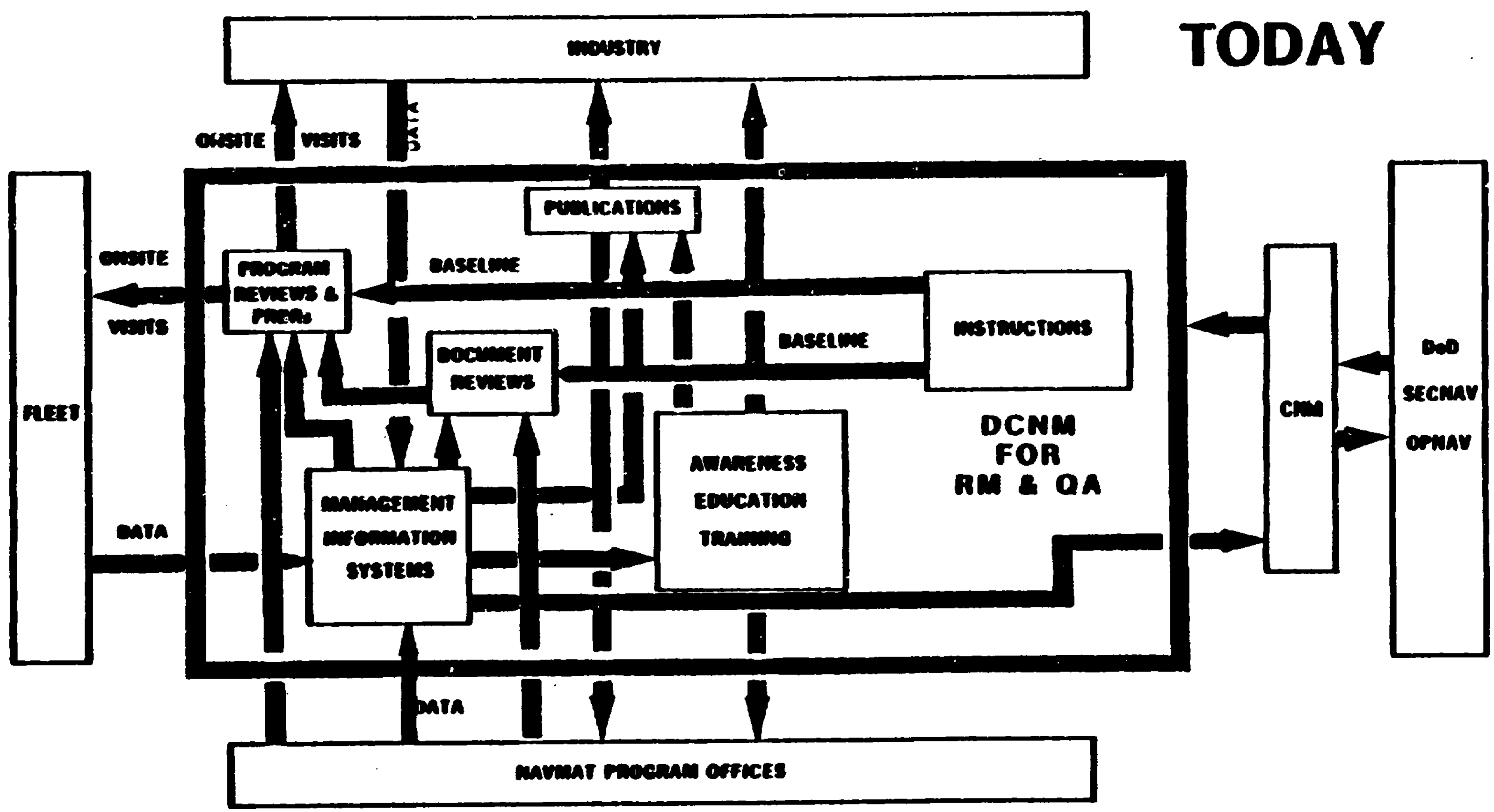
ORGANIZATIONAL STRATEGY
1980

HEADQUARTERS NAVAL MATERIAL COMMAND



MAJOR ORGANIZATION FUNCTIONS AND INTERFACES

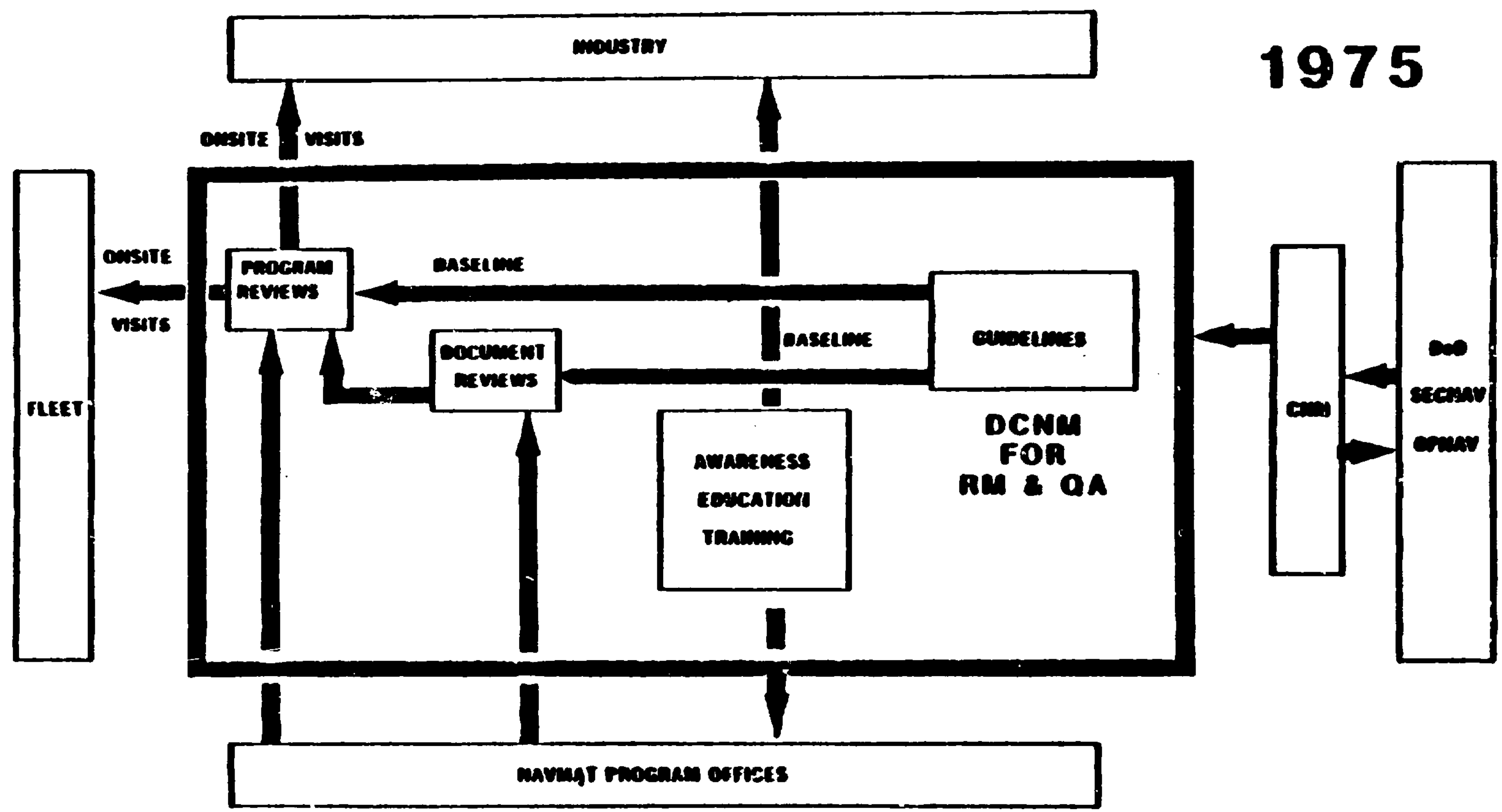
TODAY



- NEW OBJECTIVES UNDERSTOOD - - NEED FOR POLICING DIMINISHING
- INITIATED INSTRUCTIONS, MANAGEMENT INFOSYSTEM, AWARENESS PUBLICATIONS
- INITIATED PRE-PRODUCTION RELIABILITY DESIGN REVIEWS

MAJOR ORGANIZATION FUNCTIONS AND INTERFACES

1975



- POLICING VIA PROGRAM AND ACQUISITION DOCUMENT REVIEW/APPROVAL AUTHORITY
- INITIATED GUIDELINES, AWARENESS, EDUCATION, TRAINING

THE PRICE TAG

FAILURE DRIVES LOGISTICS

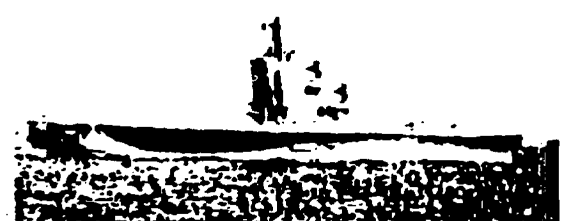
- 15,000 HARDWARE CASREPS/YR
- 1.7M AIRBORNE FAILURES/YR
- $0.5 BILLION SPARES COST/YR

RELIABILITY DEGRADES PERFORMANCE

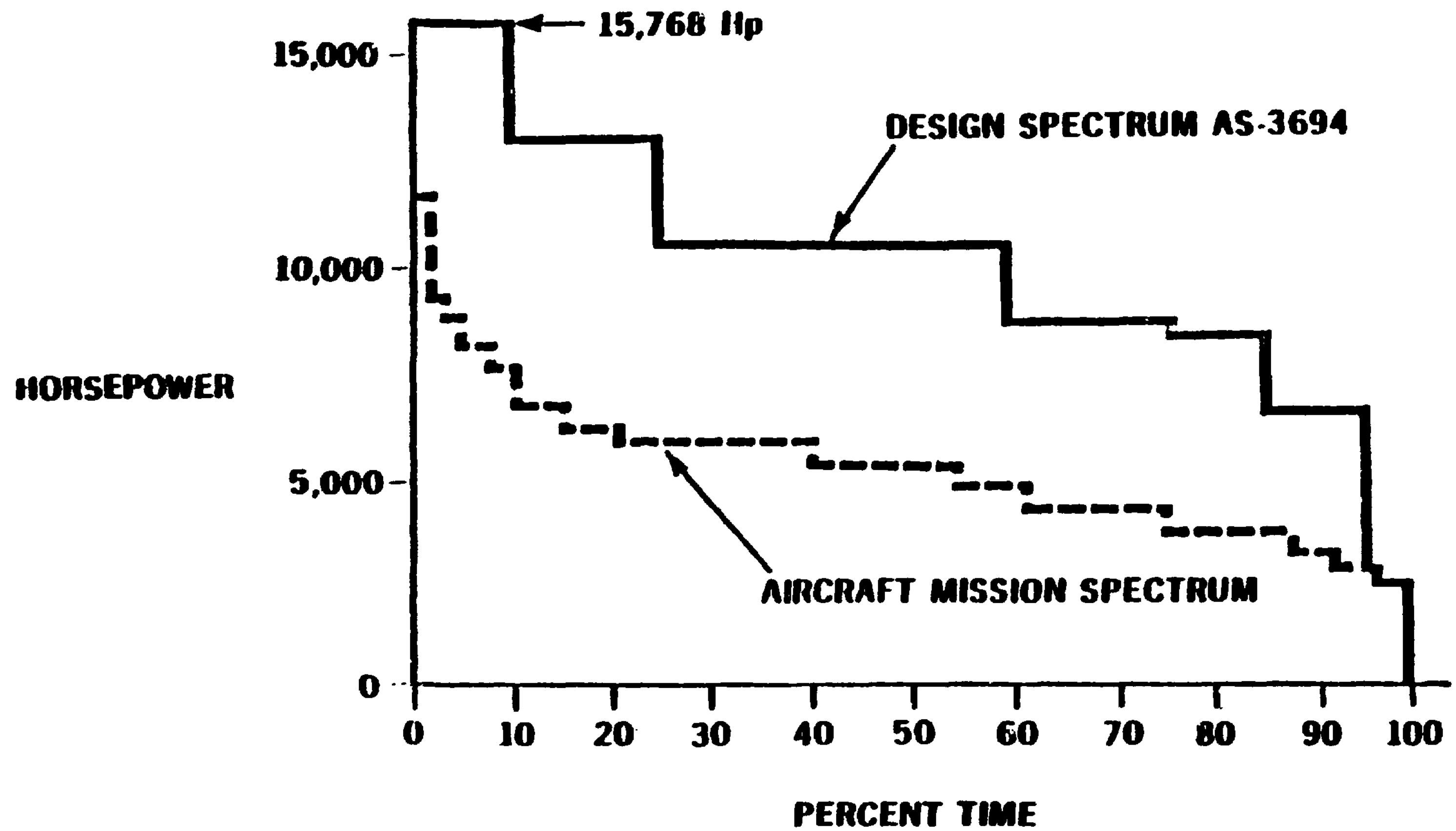
- EXCESSIVE MAINTENANCE TIME
- SUSTAINED COMBAT ENDURANCE?
- SOME SYSTEMS < 35% READINESS

GROWING SOVIET NAVAL THREAT

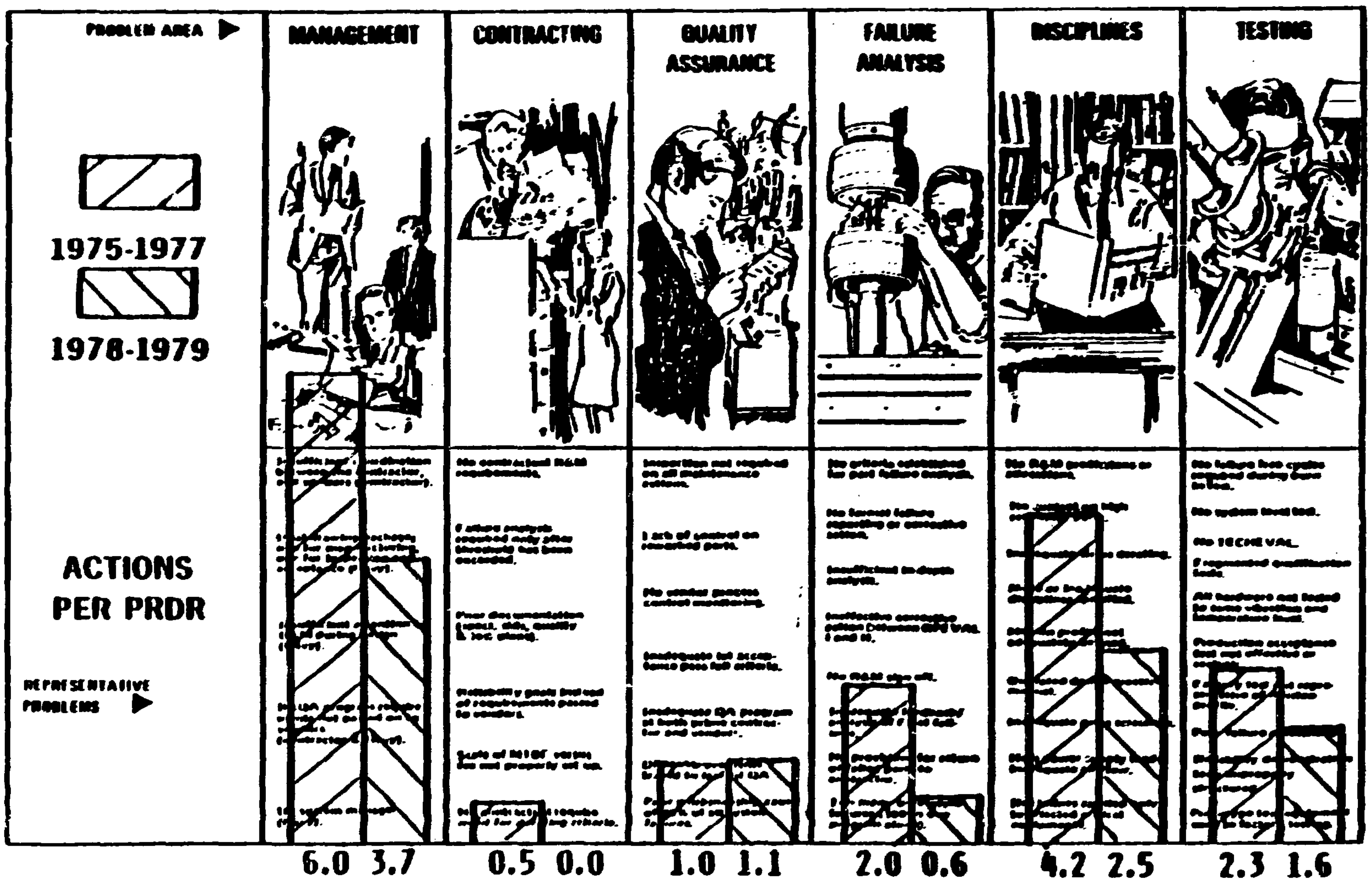
- 522 MORE WARSHIPS THAN U.S.
- SIMPLE DESIGN VS. U.S. COMPLEXITY
- TECHNOLOGICAL GAP NARROWING



TRANSMISSION DESIGN SPECTRUM STRESS DERATING

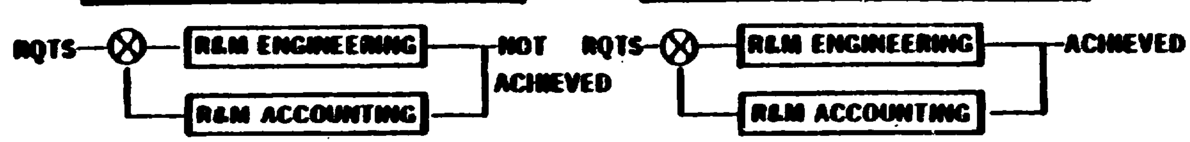


PREPRODUCTION RELIABILITY DESIGN REVIEWS



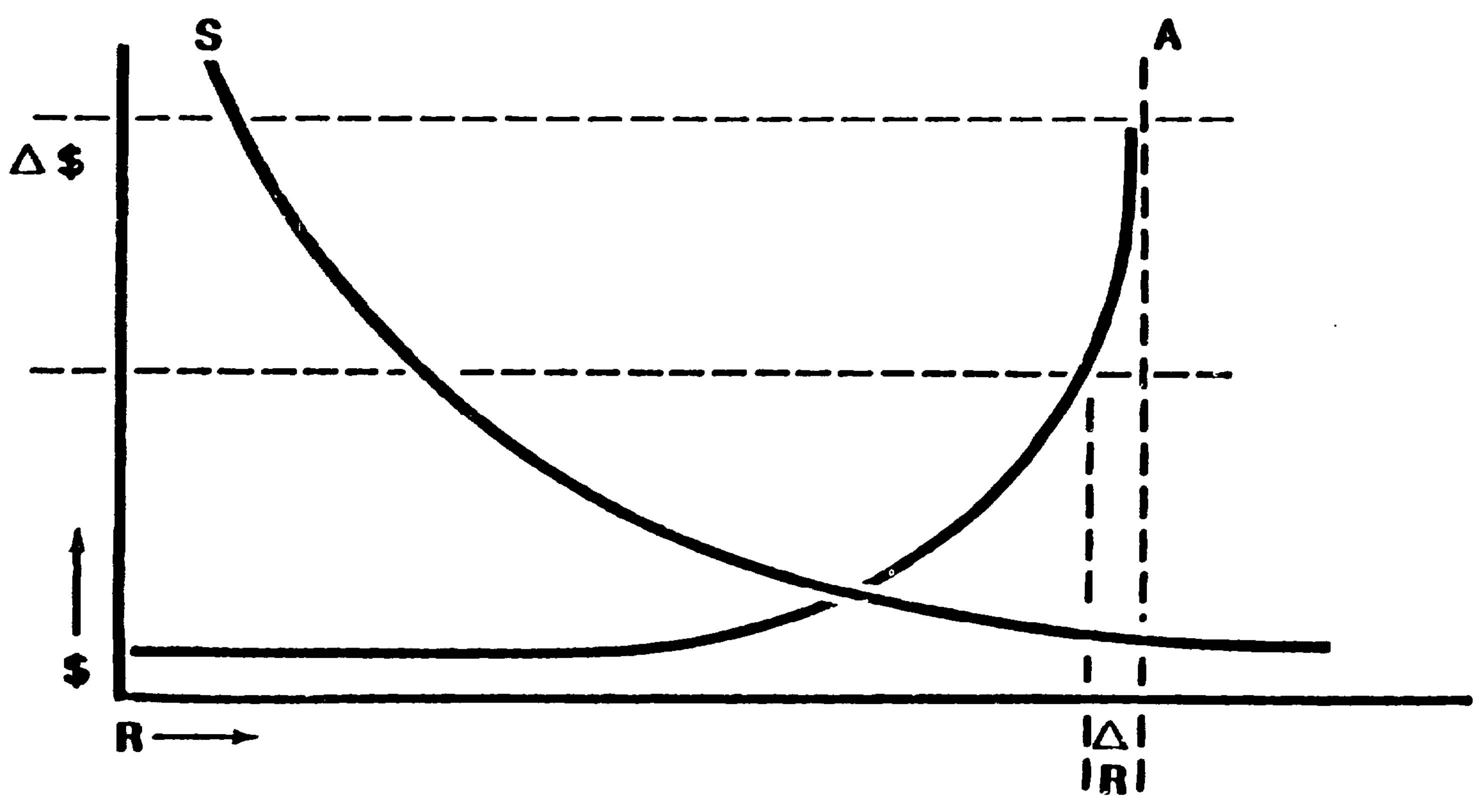
REALIGNMENT OF OBJECTIVES

	THEN	NOW
AWARENESS	PERFORMANCE, COST, SCHEDULE	PERFORMANCE AND RELIABILITY EQUAL
RESEARCH	O&M COSTS ROB R&D FUNDS	FRONT-END FUNDIN^ NEED UNDERSTOOD
SPECIFICATION	NUMBERS TO BE DEMONSTRATED	DSN-MFG REQUIREMENTS+ ALLOCATIONS
CONTRACTING	BOILERPLATE STANDARDS	TAILORED REQUIREMENTS
DESIGN	ACCOUNTING-DRIVEN	ENGINEERING FUNDAMENTALS
TESTING	UNREALISTIC BOILERPLATE STANDARDS	MISSION PROFILE AND DESIGN LIMITS
FAILURES	RELEVANCE DISCRETIONARY	NONE OVERLOOKED
MANUFACTURING	ACCOUNTING-DRIVEN	DEFECT MGT: PARTS AND WORKMANSHIP
ACCEPTANCE	RELIABILITY-MEASUREMENT-ORIENTED	DEFECT-SCREENING-ORIENTED
SUPPORT	LOGISTICS NIGHTMARE	REDUCING DEMAND



DESIGN

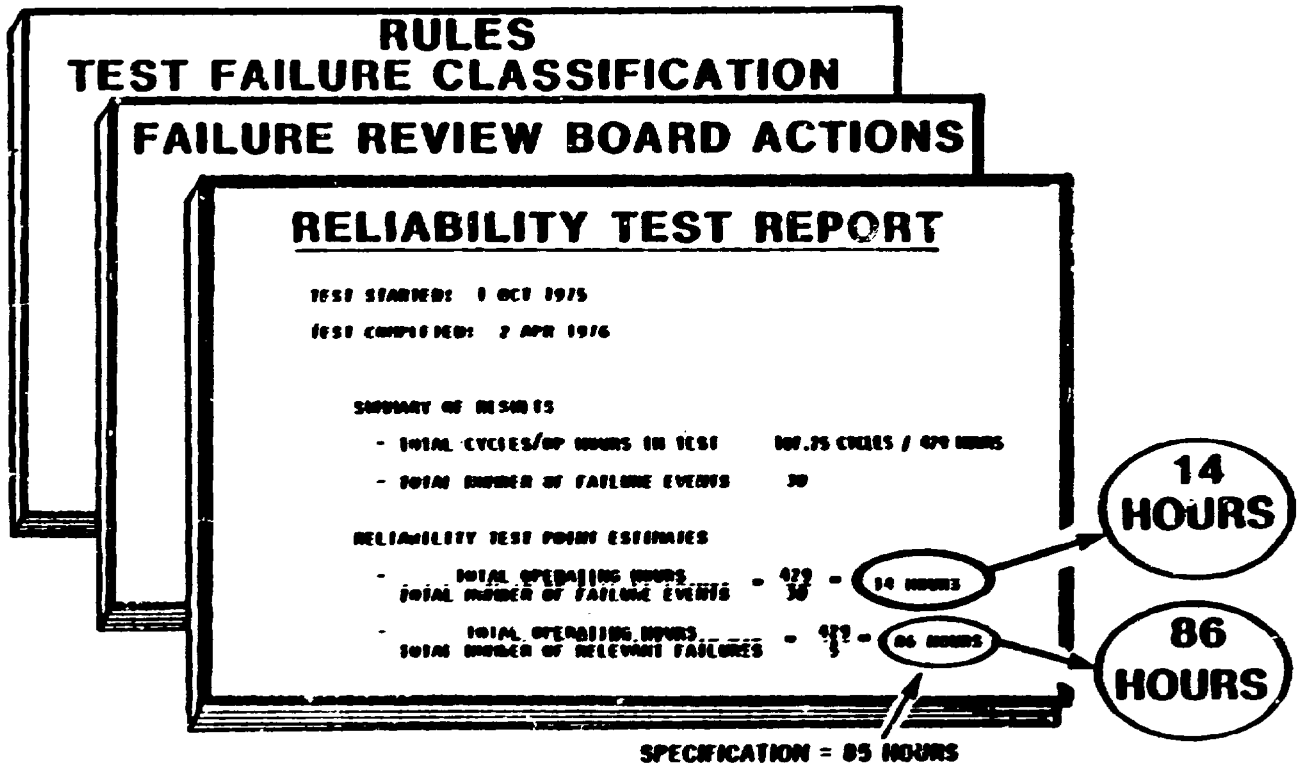
GAME OF RANDOM NINES



RELIABILITY BY MEASUREMENT

- **RELIABILITY BY NUMBER**

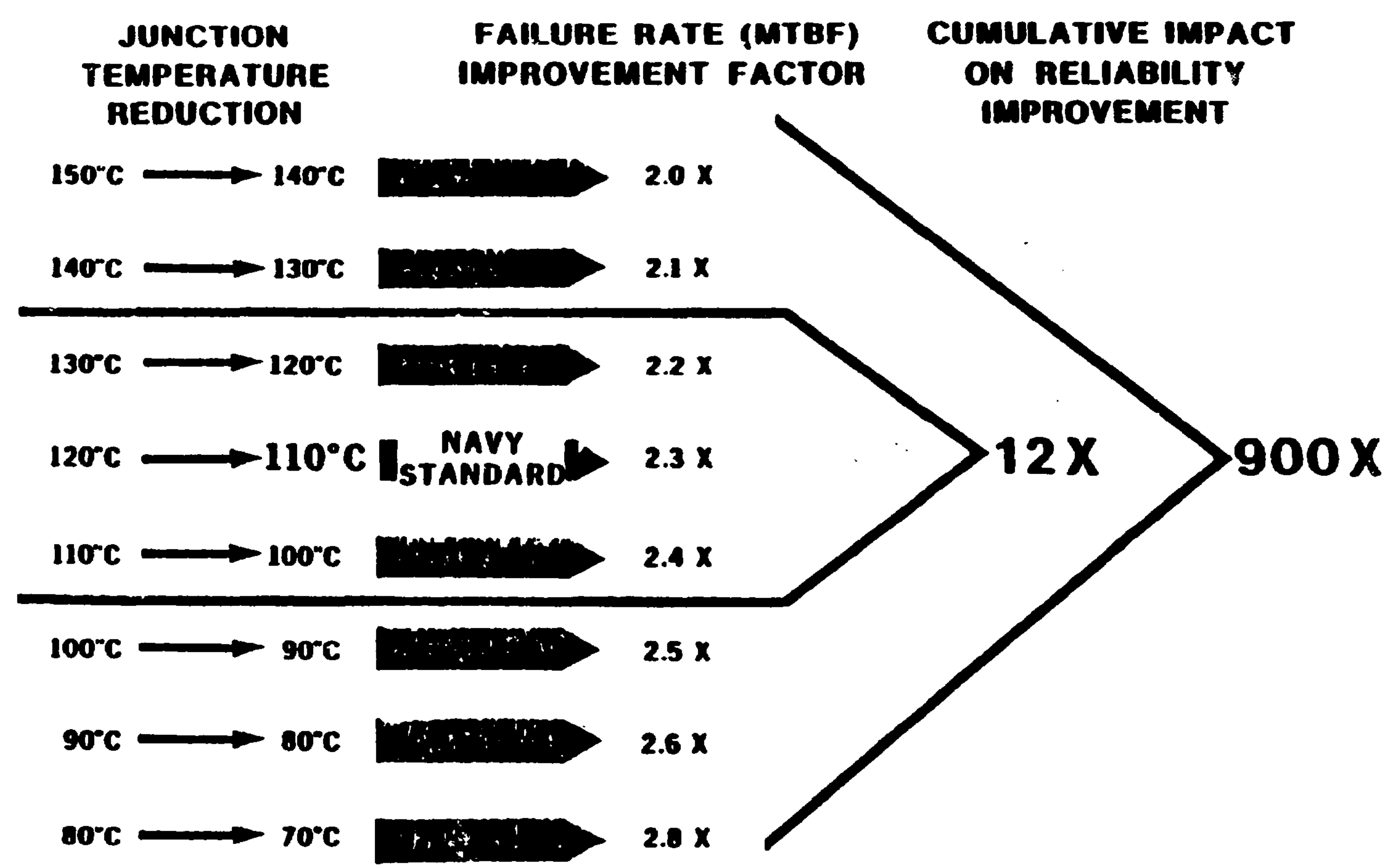
  (SPECIFICATION DEMONSTRATION → SCORING → LAWYERS)



MATERIAL ACQUISITION FUNDAMENTALS

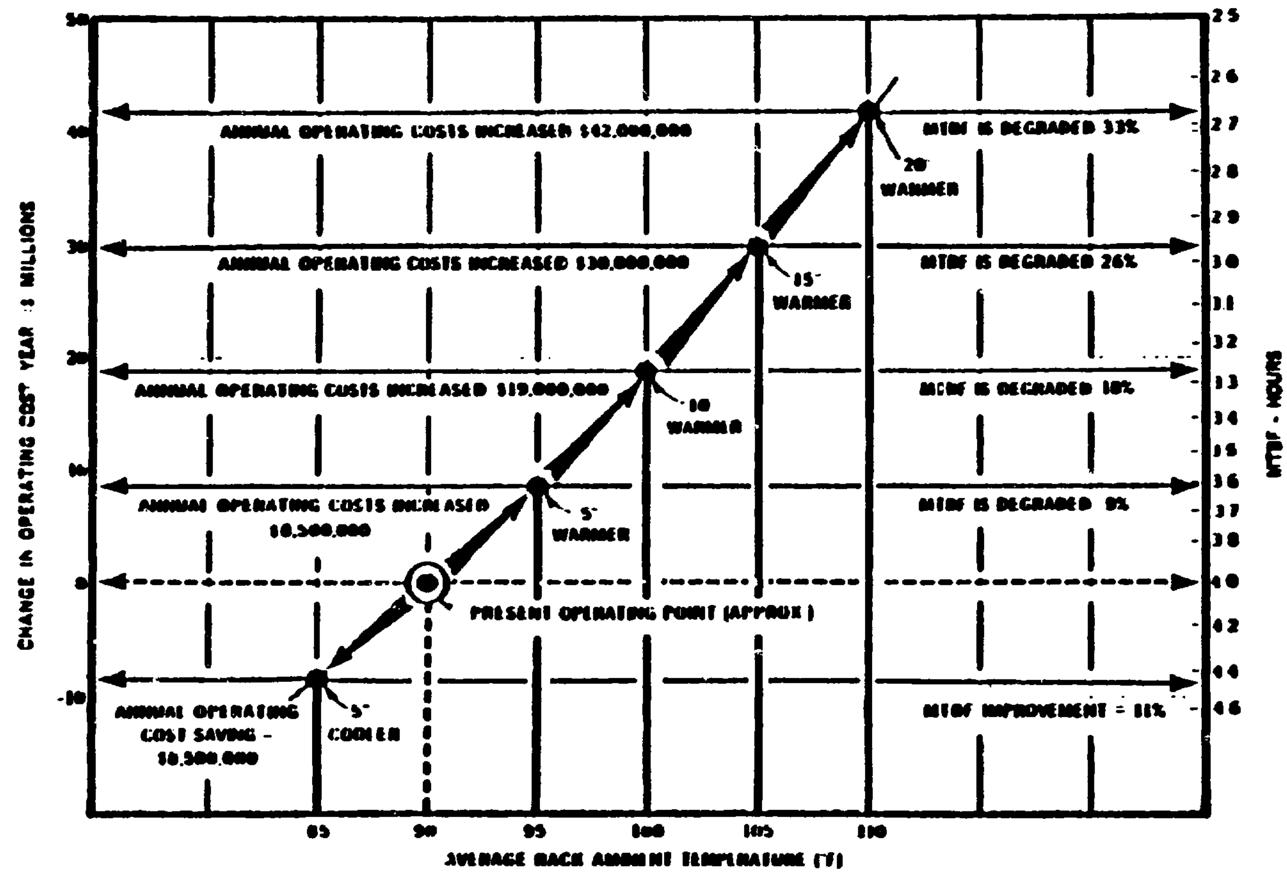
- MISSION PROFILE DEFINITION
- STRESS ANALYSIS
- DERATING CRITERIA
- WORST CASE ANALYSIS
- SNEAK CIRCUIT ANALYSIS
- PREDICTION/ALLOCATIONS
- FAILURE MODES & EFFECTS ANALYSIS
- TEST, ANALYZE, & FIX WITH CLOSED LOOP REPORTING
- DESIGN REVIEWS
- MISSION PROFILE QUALIFICATION TEST

JUNCTION TEMPERATURE IMPACT ON SEMICONDUCTOR RELIABILITY

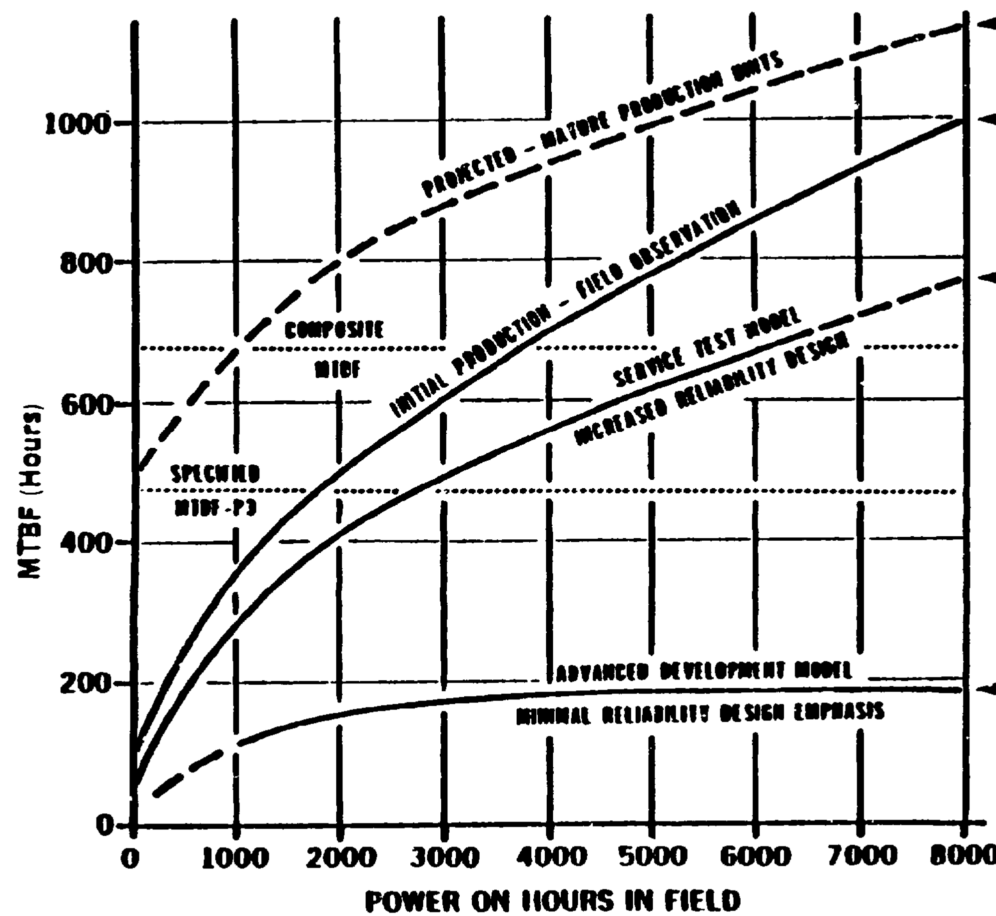


OPERATING TEMPERATURE IMPACT

IMPACT OF OPERATING TEMPERATURE ON ANNUAL OPERATING COST AND MTBF (BASED ON 200 AIRCRAFT)



AN/UYS-1 ANALYZER UNIT RELIABILITY PERFORMANCE IN SERVICE USE



END ITEM VISIBILITY, RANDOM VIBRATION, & FIELD FAILURE DATA COLLECTION

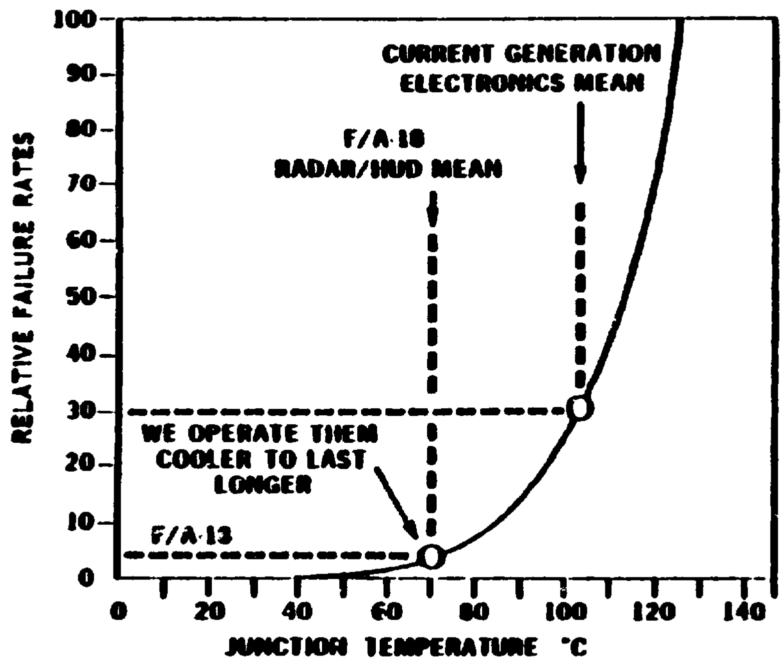
FIELD FAILURE CATEGORIES
- WORKMANSHIP - 50%
- COMPONENT FAILURE - 30%
- OTHER - 20%

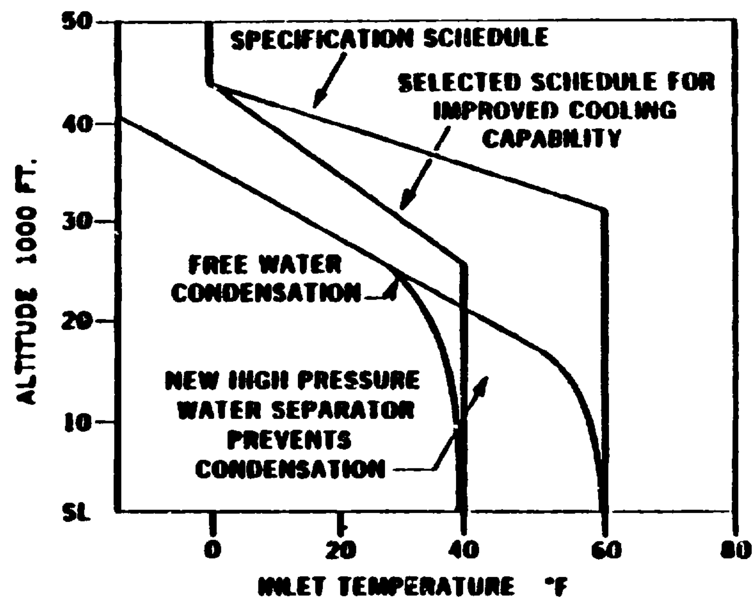
RELIABILITY BY DESIGN - THE NEW LOOK:

CONTRACT REQUIREMENTS, RELIABILITY ANALYSIS AND EVALUATION, THERMAL & ELECTRICAL DERATING CRITERIA, AND NAVMAT/CONTRACTOR INTERFACE TO MINIMIZE FAILURE

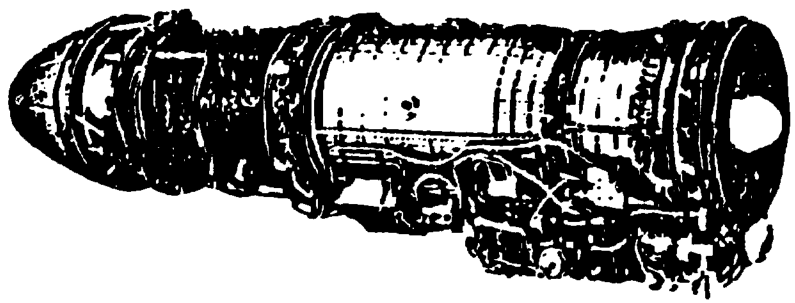
RELIABILITY BY CHANCE

TRADEOFF FOR RELIABILITY





F-404 ENGINE RELIABILITY



F404 (Hornet) 14,300 Parts

AND RELIABILITY FOUR TIMES HIGHER!

Same Thrust Class
- ~3/4 the Length
- ~1/2 the Weight
- 7700 Fewer Parts

8 Fewer Stages
- 7 Compressors
- 1 Turbine

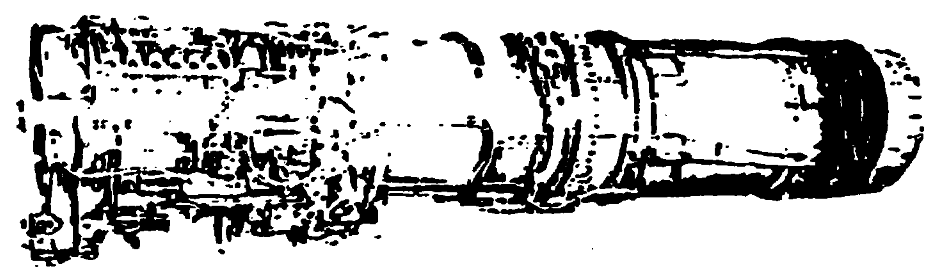
3 Fewer Variable Stators

Simple Gearbox
- 38 Fewer Bearings
- 28 Fewer Shafts

Simple Fuel System
- 29 Fewer Pipes

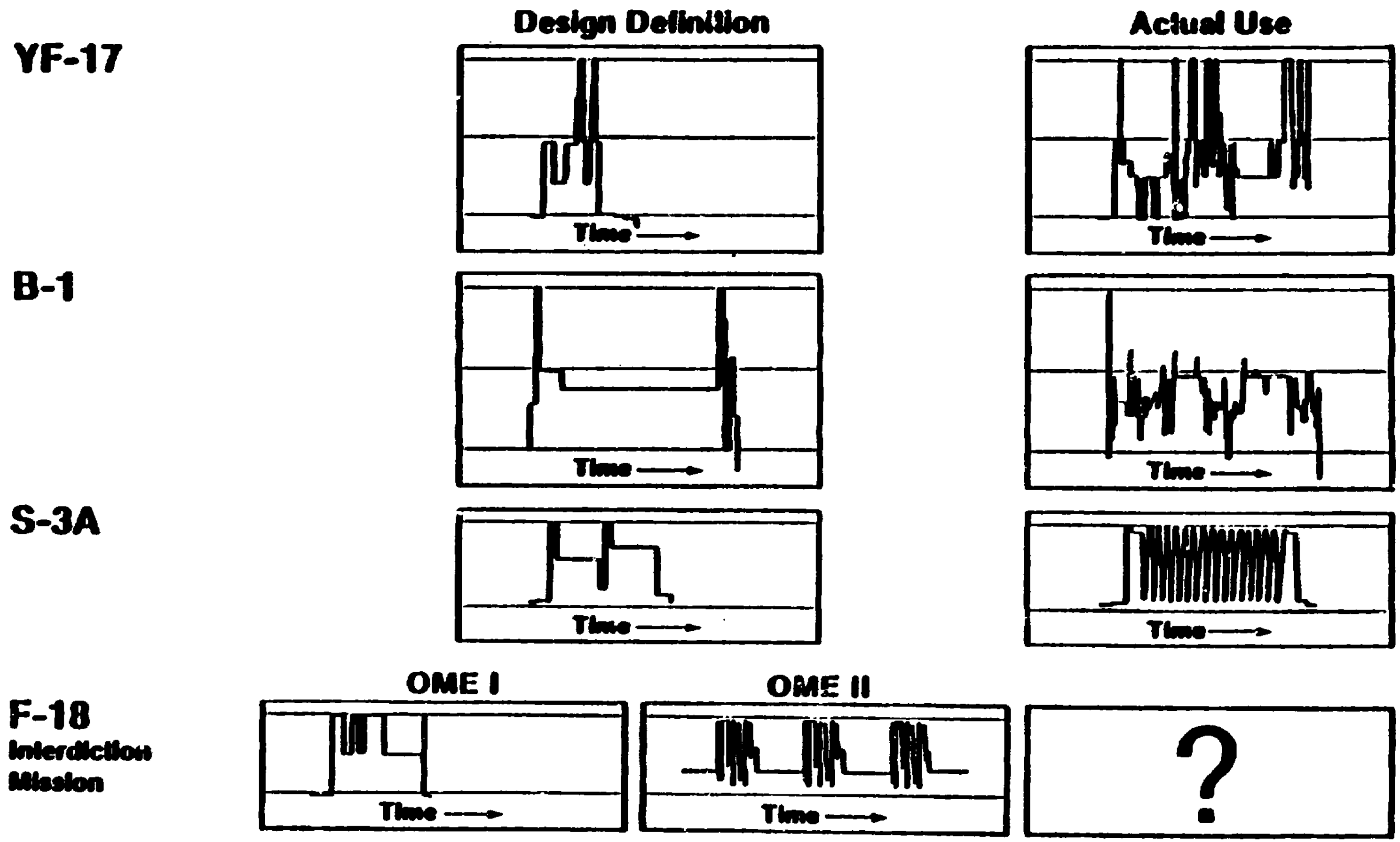
One Combustor Liner vs. 10 Cans

Proven Base
- Over 2500 Hrs (Factory and Flight) on YJ101

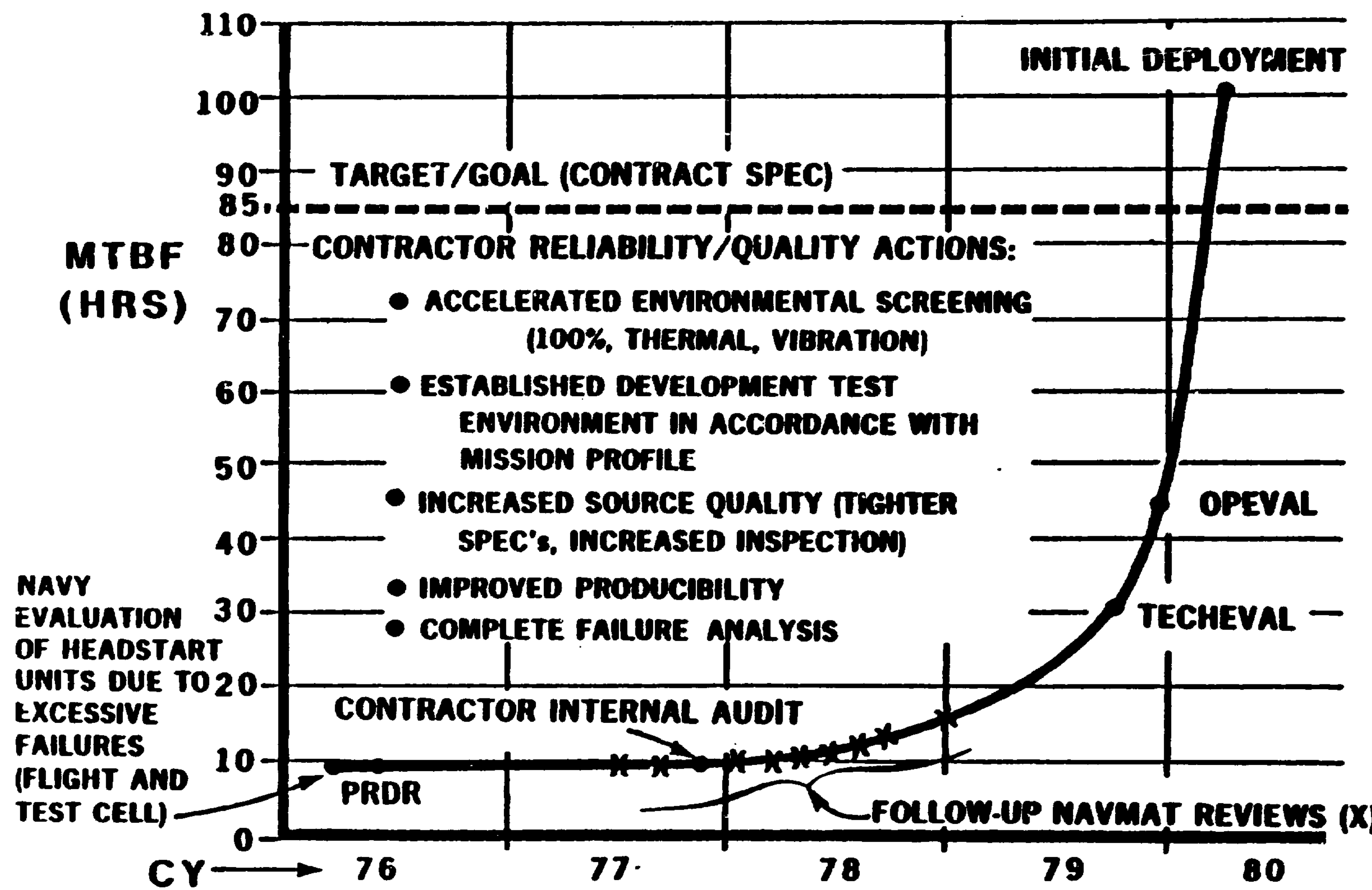


J79 (Phantom) 22,000 Parts

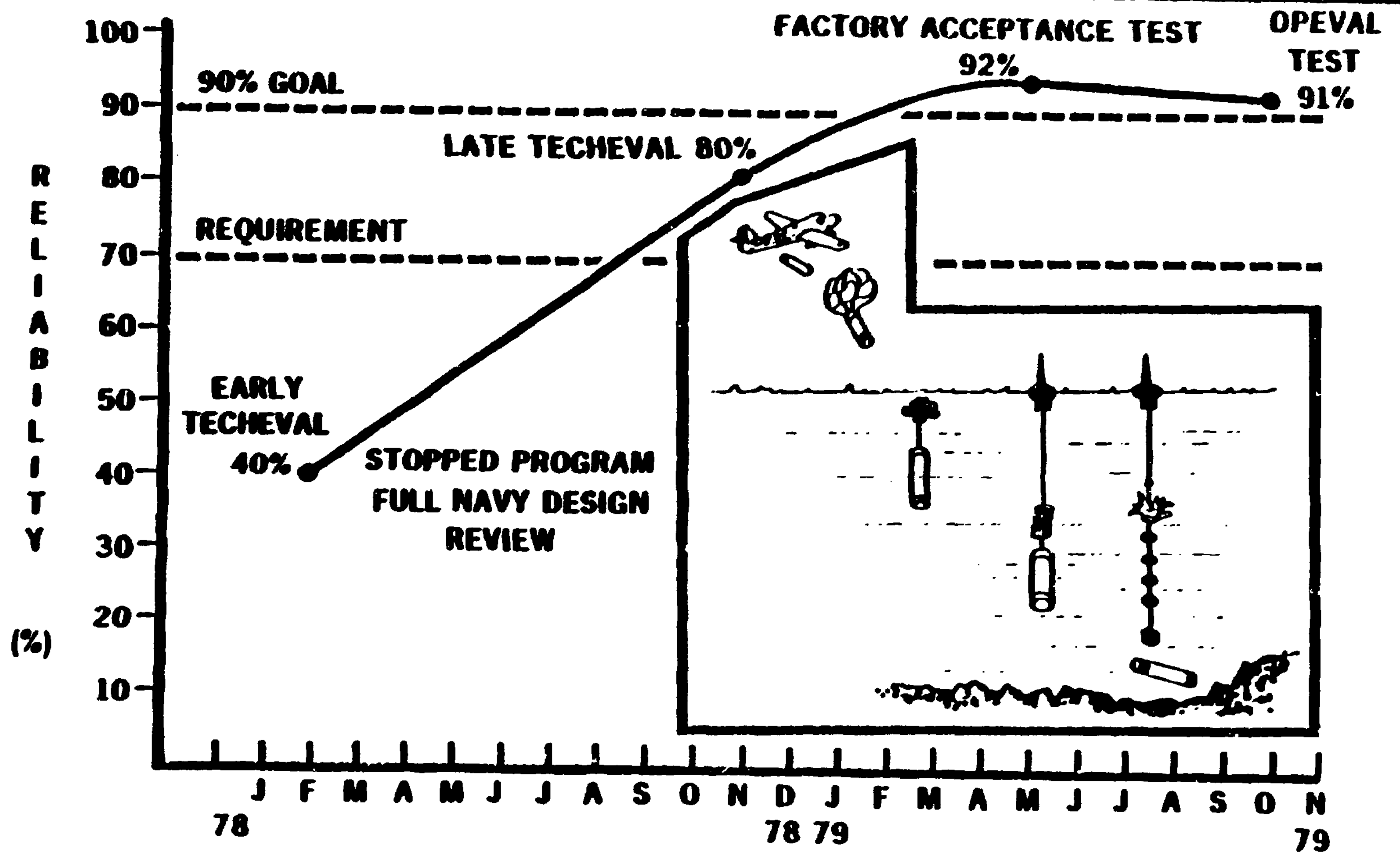
Lessons Learned
Mission Profiles May Change
Power Usage



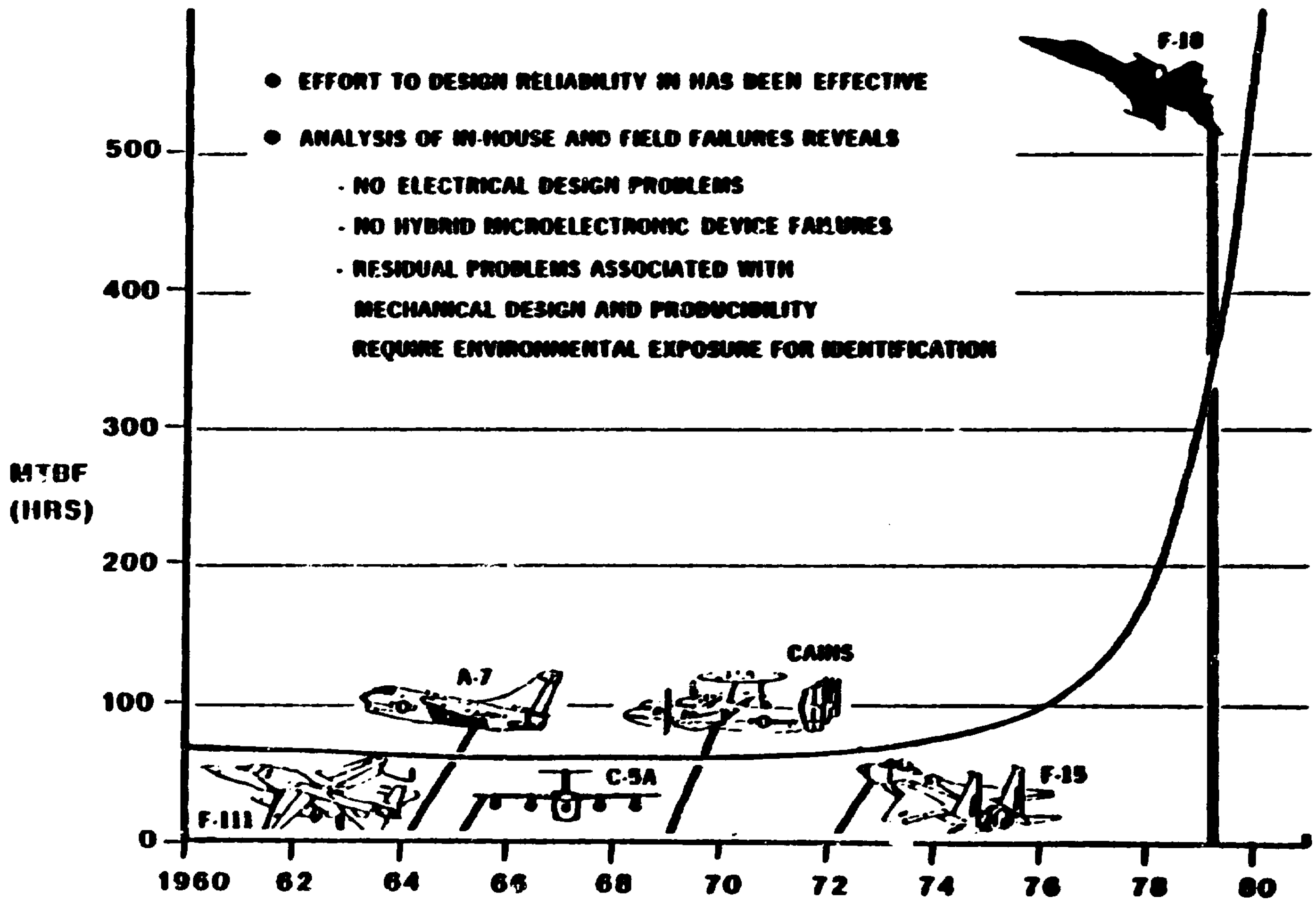
A6E TRAM DETECTING AND RANGING SET (DRS) RELIABILITY



VERTICAL LINE ARRAY DIFAR (VLAD) AN/SSQ-77 SONOBUOY



F-18 INS DESIGN EXPERIENCE



DECISION MAKING-A CHALLENGE FOR RELIABILITY MANAGEMENT

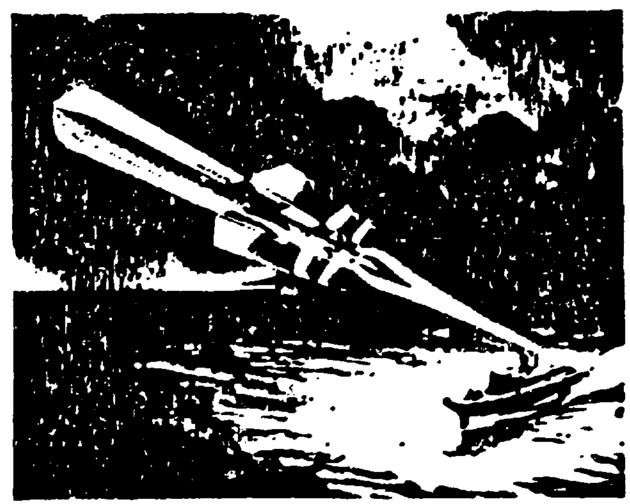
HARPOON MISSILE AVAILABILITY & RELIABILITY

CAPTIVE CARRY AVAILABILITY

- AIR (BASED ON 3421 CARRY HRS)
  - 171 HRS MTBF < 250 HRS
  - 92% AVAIL AFTER 14 HR FLIGHT < 95%
  - 89% AVAIL AFTER 14 HR FLIGHT (90% CONF.) < 92%
- SHIP (BASED ON 1371 CARRY DAYS)
  - 196 DAYS MTBF
  - 6% AVAIL AFTER 18 MOS < 90%
  - 20% AVAIL AFTER 6 MOS (90% CONF.) < 90%
  - 3% AVAIL AFTER 24 MOS
- ENCAP (BASED ON 395 CARRY DAYS)
  - 395 DAYS MTBF
  - 25% AVAIL AFTER 18 MOS < 90%
  - 17% AVAIL AFTER 6 MOS (90% CONF.) < 90%
  - 16% AVAIL AFTER 24 MOS

IN–FLIGHT RELIABILITY

- AIR: 62% < 90%
- SHIP: 100% > 90%
- ENCAP: 88% < 90%
- COMBINED: 80% < 90%



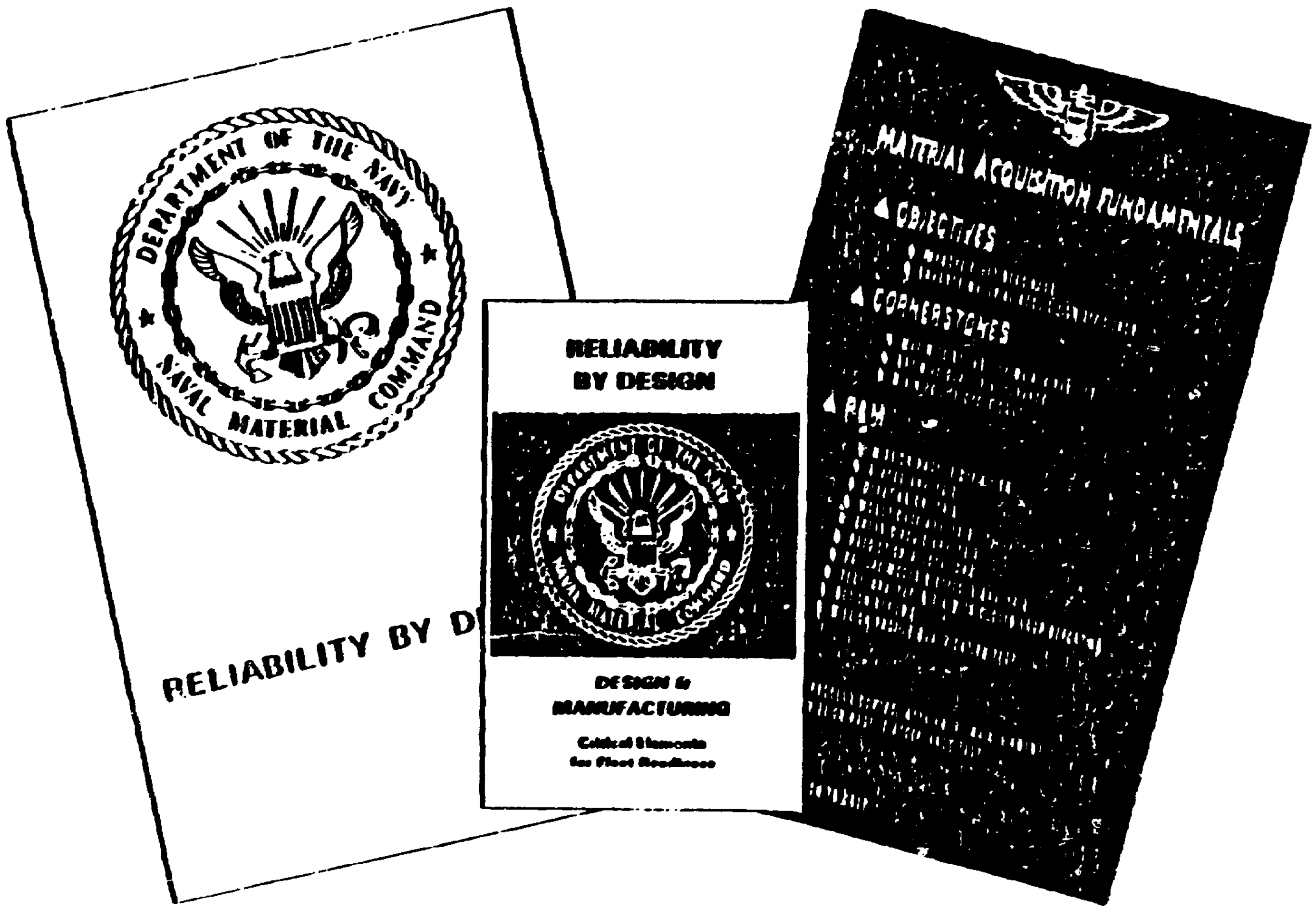
DECISION MAKING
A PRACTICAL APPROACH FOR RELIABILITY MANAGEMENT

HARPOON RISK ASSESSMENT

RISK ASSESSMENT \ ENGINEERING DATA		DESIGN STRESS	OPEN/ CLOSED FAILURE	WAIVERS DEVIATIONS	MFG DISCREP-ANCIES	QUALIFI-CATION STATUS	QUALITY TREND DATA	CONFIGU-RATION STATUS	TEST EQUIP.
HIGH	MDAC		R		R		R	R	
	TI		R						R
MODERATE	MDAC					Y			
	TI				Y	Y			
LOW	MDAC	G		G					G
	TI	G		G			G	G	
CONCLUSIONS		BASIC DESIGN IS SOUND	FAILURE CLOSEOUT NEEDS IMPROVE-MENT	NO ACTION REQUIRED	IMPROVE LOWER LEVEL TEST SCREENS	REEVAL. QUAL. ENVIRON. VS. MISSION ENVIRON.	IMPROVE MANAGE-MENT VISIBILITY	MDAC TO GO TO BLOCK CONTROL	STOP USE OF VOTING LOGIC FOR PASS CRITERIA

RELIABILITY AWARENESS PUBLICATIONS

INDIVIDUAL RELIABILITY AWARENESS



INDUSTRY IN TRANSITION
DESIGN

R 1975 ———————— 1985 G

REPRESENTATIVE CONTRACTORS

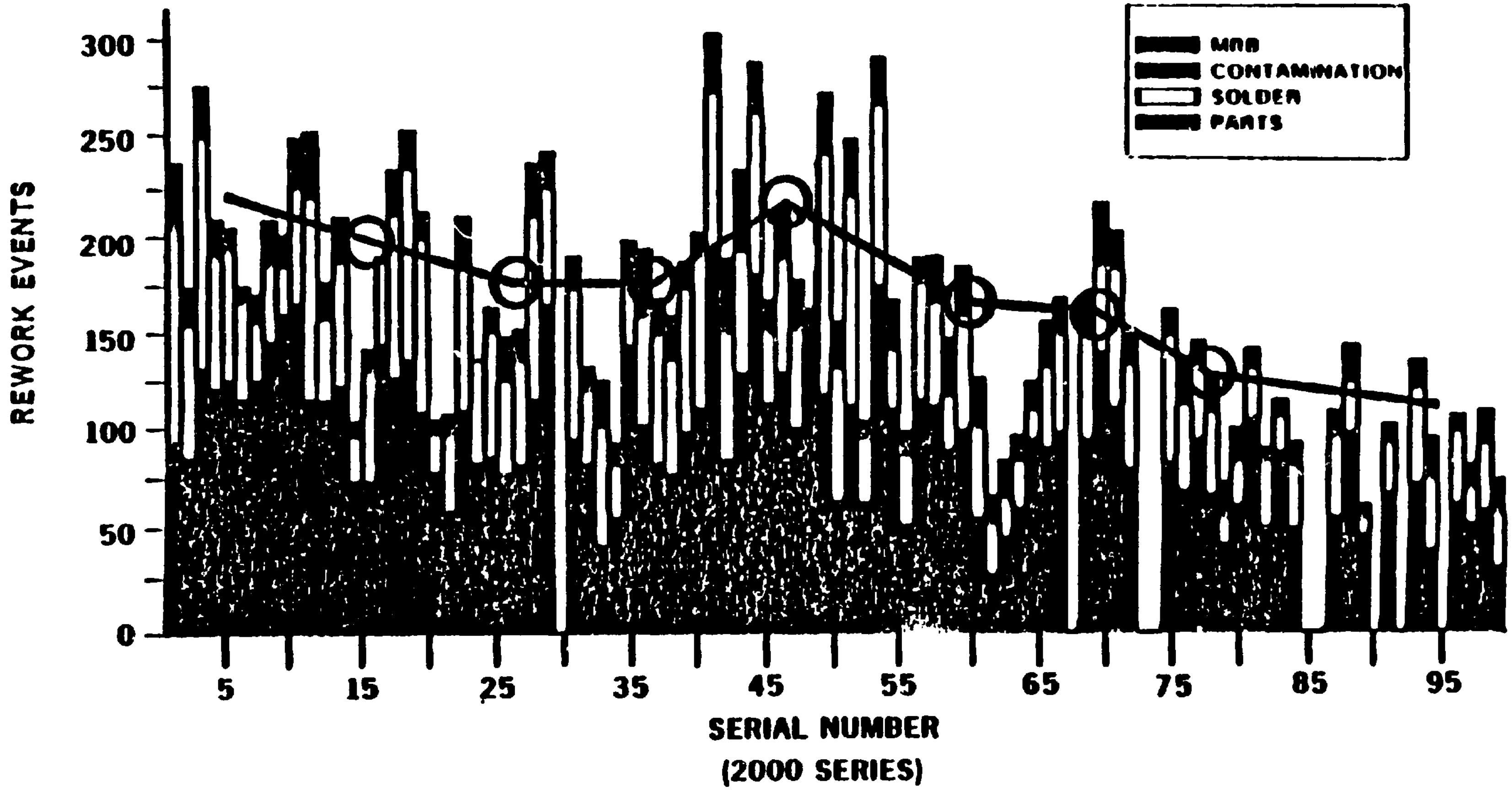
	1	2	3	4	5	6	7	8	9	10
POLICY IMPORTANCE OF DESIGNING RELIABLE EQUIPMENT REFLECTED IN CORPORATE STATEMENTS	Y	G	G	Y	G	G	G	G	R	G
ATTITUDES RECOGNIZES THE NEED TO IMPROVE RELIABILITY DESIGN EFFORTS	G	G	G	G	G	G	G	G	G	G
AWARENESS RECOGNIZES THE IMPORTANCE OF DESIGNING IN RELIABILITY	R	G	G	G	G	G	G	G	R	G
STANDARDS FORMAL BODY OF CONSERVATIVE AND PROVEN RELIABILITY DESIGN PRACTICES	R	G	G	G	G	G	Y	G	Y	G
MOTIVATION FORMAL PROGRAM FOR ACHIEVEMENT AND RECOGNITION	R	R	R	R	R	R	R	R	R	R

R ACTION REQUIRED Y IN PROCESS G ACHIEVED

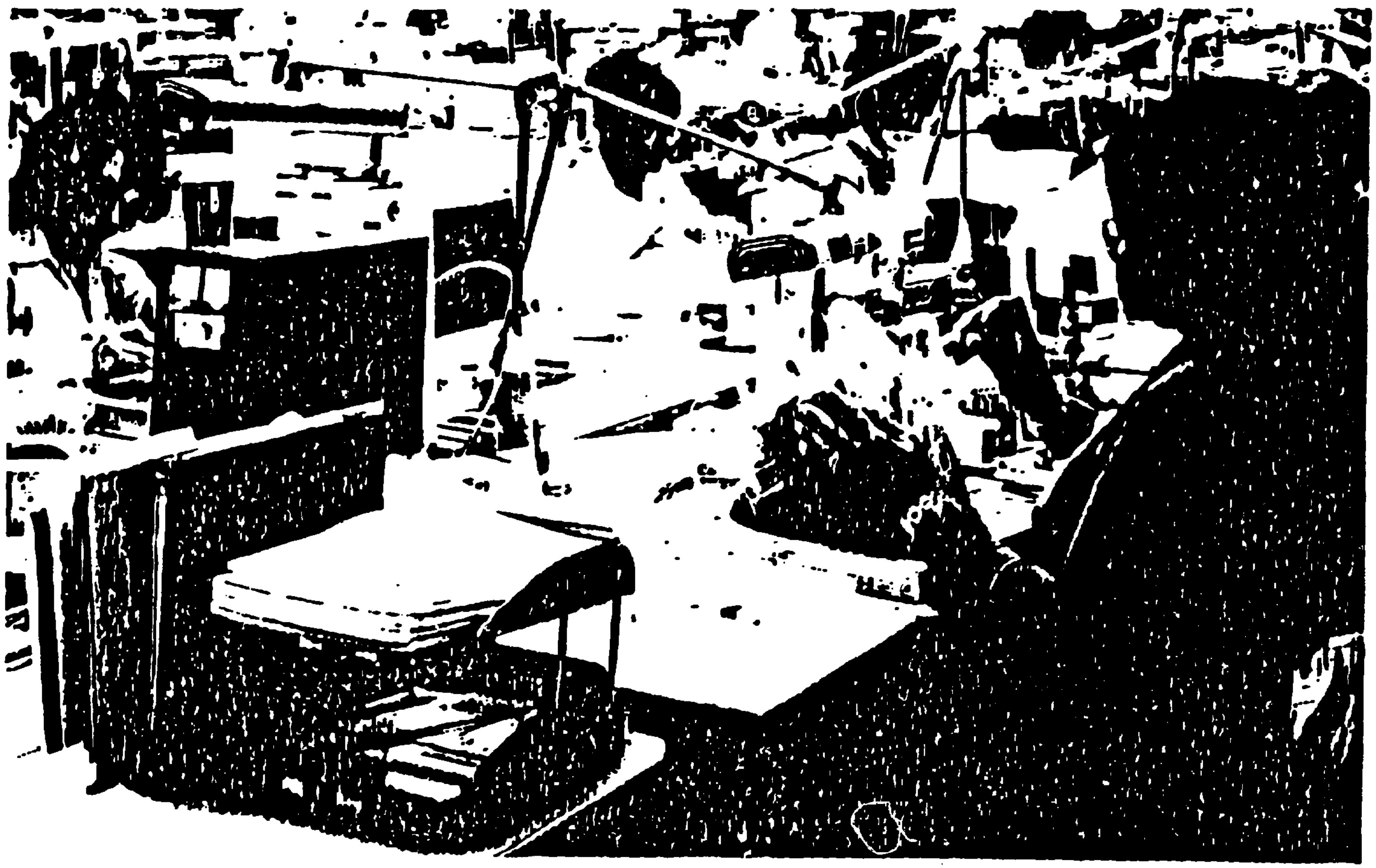
MANUFACTURING

BUILD TO PRINT

MANUFACTURING
END ITEM VISIBILITY



PRODUCTION LINE
OLD CONFIGURATION



PRODUCTION LINE
NEW CONFIGURATION

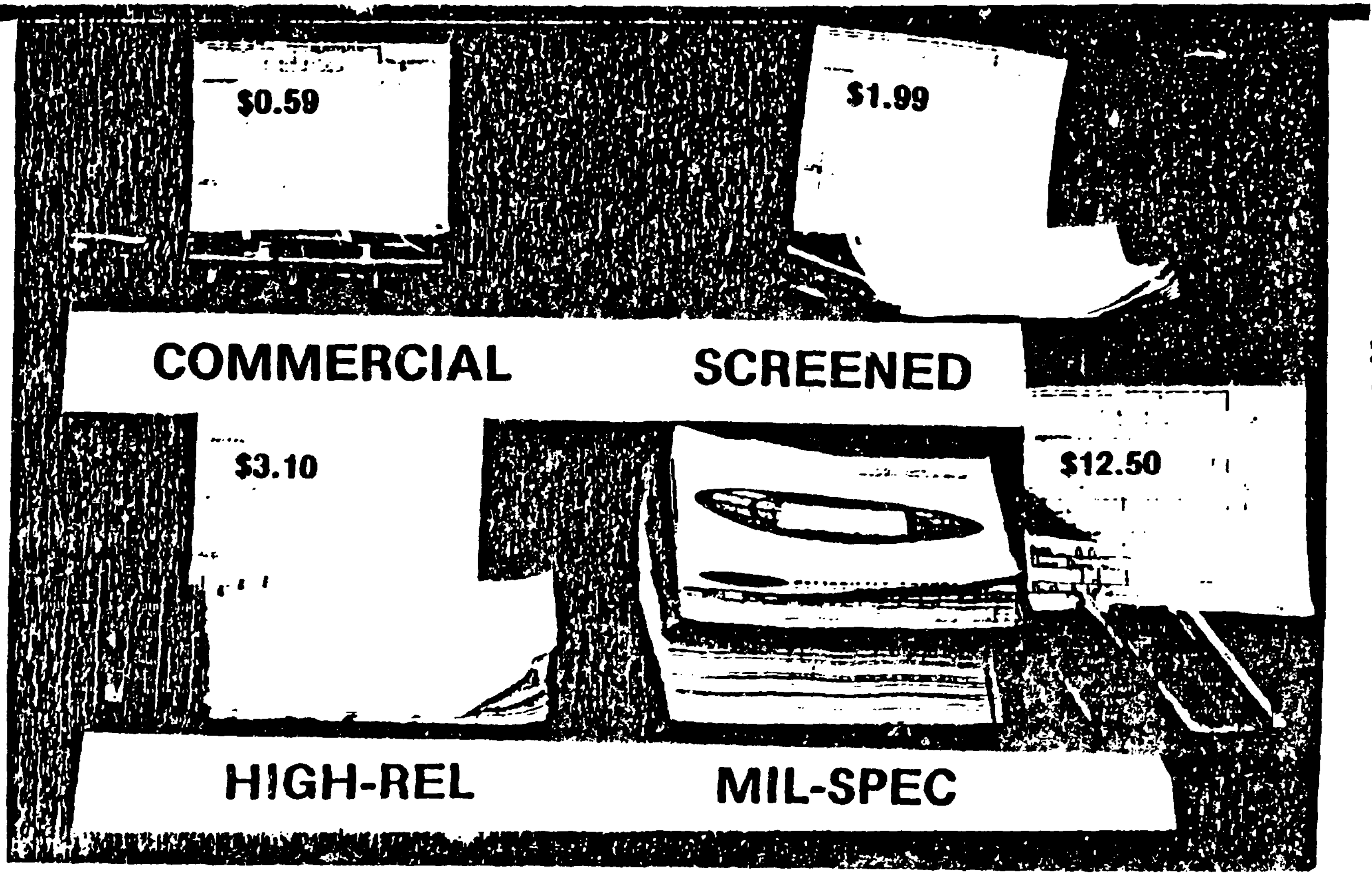
UNRELIABLE SEMICONDUCTORS

MAJOR CONTRIBUTOR

TO

PARTS PROBLEMS

THE COST OF QUALITY



RESULTS OF PIN TESTING

LOT NO.	TOTAL PARTS TESTED	TOTAL FAILURES	% REJECTED
1	476	12	2.5
2	1,300	62	4.8
3	3,076	399	12.9
4	2,604	329	12.6
5	15	0	
6	1,049	47	4.5
7	2,752	11	0.4
8	1,627	115	7.1
	12,899	975	7.5

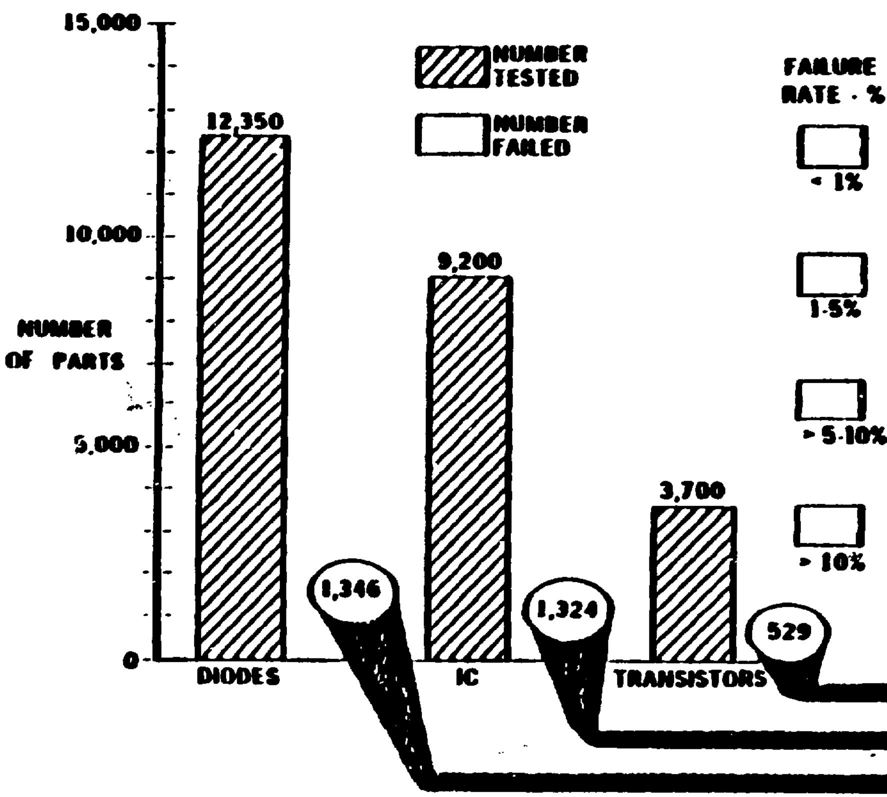
INTEGRATED CIRCUITS

PRE-CAP VISUAL SOURCE INSPECTION RESULTS

MFG	ACCEPTED	REJECTED	% REJECTED
1	33,000	15,200	32
2	38,000	12,700	25
3	1,389	3,597	72
4	1,219	2,268	65
5	2,804	448	14
6	446	95	18

PART SCREENING RESULTS

MIL–SPEC PARTS



TYPE OF TEST	TRAN-SISTOR	IC	DIODE
RECEIVING VISUAL	1.3	1.2	1.6
INITIAL ELECTRICAL			
HIGH TEMP, BAKE			
THERMAL SHOCK		4.3	
TEMP, CYCLING			
ACCELERATION			
SEAL			
PRE-HTRB ELECTRICAL	2.6		
HIGH-TEMP, REVR, BIAS			
PRE BURN-IN ELECTRICAL	1.4	1.8	1.4
BURN-IN			
POST-BURN ELECTRICAL	4.1	6.9	3.1
GROUP-A ELECTRICAL		16.4	
RADIOGRAPHIC	7.9	5.3	2.5
PIND	21.4	15.7	
FINAL ELECTRICAL			
FINAL VISUAL	3.0		
OTHER	1.6		
OVERALL	14.3%	14.4%	10.9%

MANUFACTURING BURDEN

ALERT:
(T3-A-79-06)

243 DEVICES OUT OF A LOT OF 425 PIECES FAILED INCOMING INSPECTION FUNCTIONAL TEST AT ROOM AMBIENT TEMPERATURE, ON SITEK 3200 TESTER. INTERNAL VISUAL (DECAP) INSPECTION REVEALED TWO DIFFERENT DIES IN PACKAGES WITH IDENTICAL JAN MARKING. FIGURE 1 SHOWS DIE FOR UNITS THAT PASSED, AND FIGURE 2 SHOWS THE DIE FOR UNITS THAT FAILED TEST.

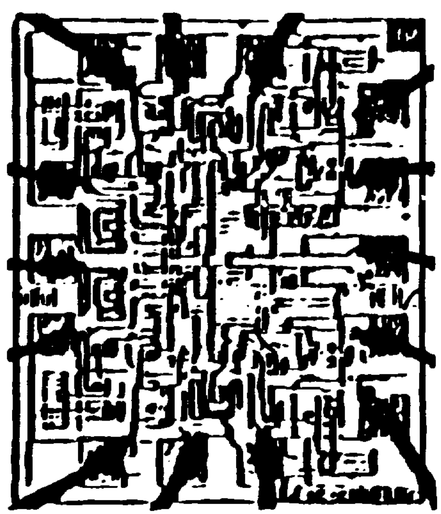


FIGURE 1 - GOOD PARTS

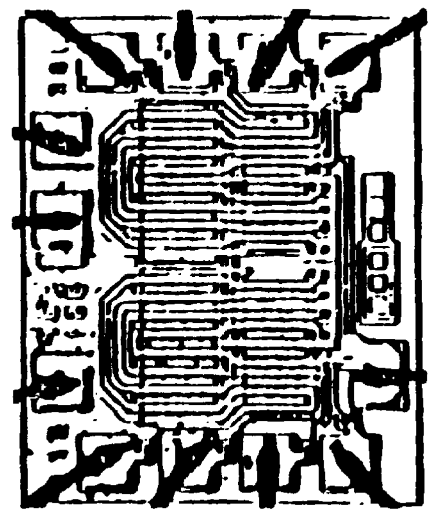


FIGURE 2 - NON-CONFORMING PARTS

<u>MANUFACTURING RESPONSE</u>: "THIS SITUATION OF MIXED PARTS DOES NOT CONSTITUTE A RELIABILITY PROBLEM. ALL OF THE INCORRECT DEVICES WOULD BE DETECTED AT A USER'S INCOMING TESTING OR AT BOARD LEVEL CHECKOUT."

MANUFACTURER'S REDUCED INTEREST IN MIL-SPEC PROCESSING

- LIMITED DoD MARKET
  - 10% BY COST
  - 2-4% BY VOLUME
- "MORE TROUBLE THAN WORTH"

JAPAN'S PENCHANT FOR RELIABILITY

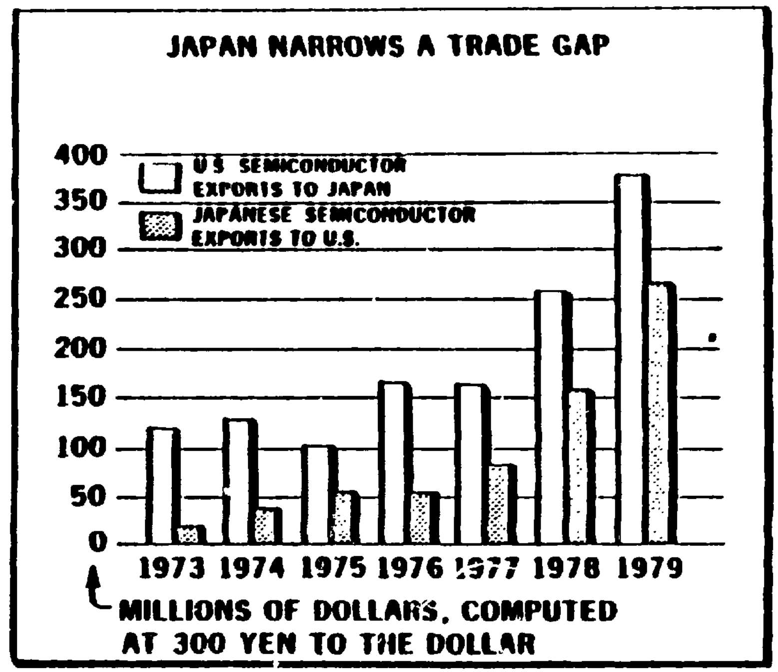
JAPAN PRODUCES RELIABLE SEMICONDUCTORS BY DESIGN, NOT BY CHANCE:
DEFECT PREVENTION, NOT DEFECT DETECTION

EXAMPLE: BETTER, MORE EXPENSIVE PRODUCTION MASKS FOR CHIPS

RESULT: JAPANESE REJECTION RATES ONE-HALF TO ONE-TENTH U.S. RATES

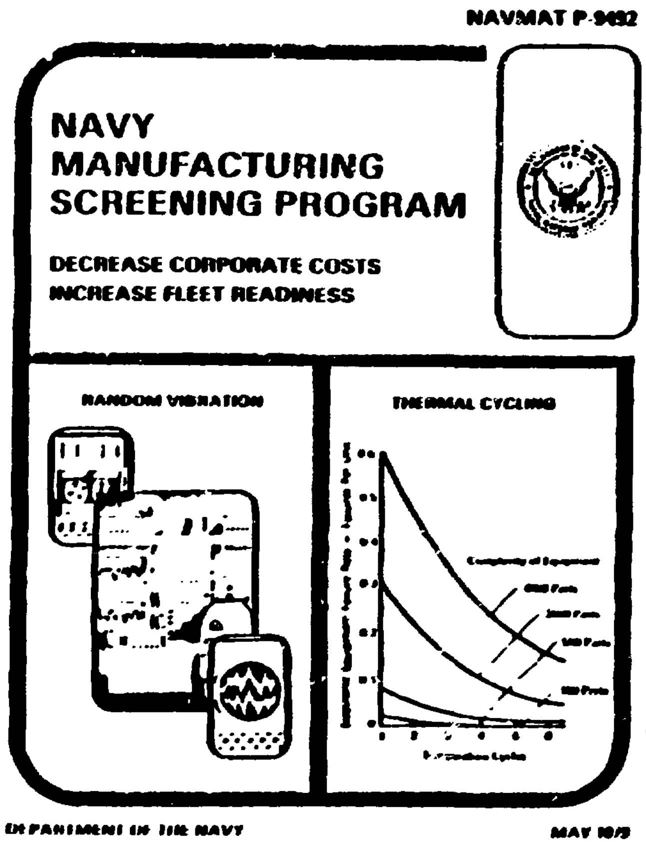
CONCLUSION: UNWILLINGNESS OF SOME U.S. VENDORS TO PRODUCE RELIABLE SEMICONDUCTORS IS COSTING THEM NOT ONLY LOSS OF MILITARY BUSINESS BUT POTENTIALLY OTHER CUSTOMERS AS WELL

• EVIDENCE:



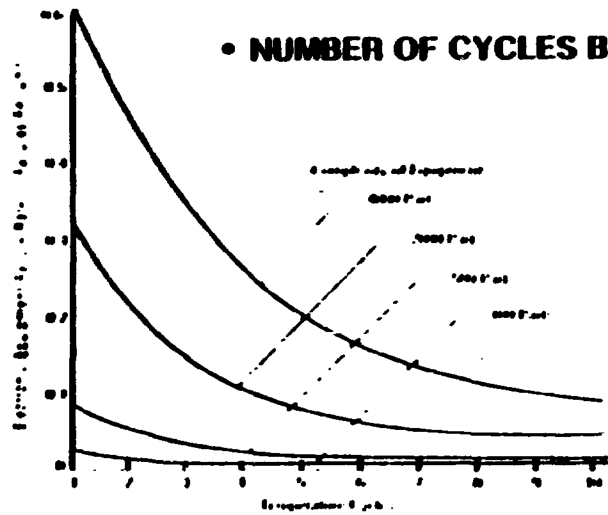
• SOURCE: BUSINESS WEEK, 3 DECEMBER 1979

NAVY MANUFACTURING SCREENING PROGRAM (P-9492)



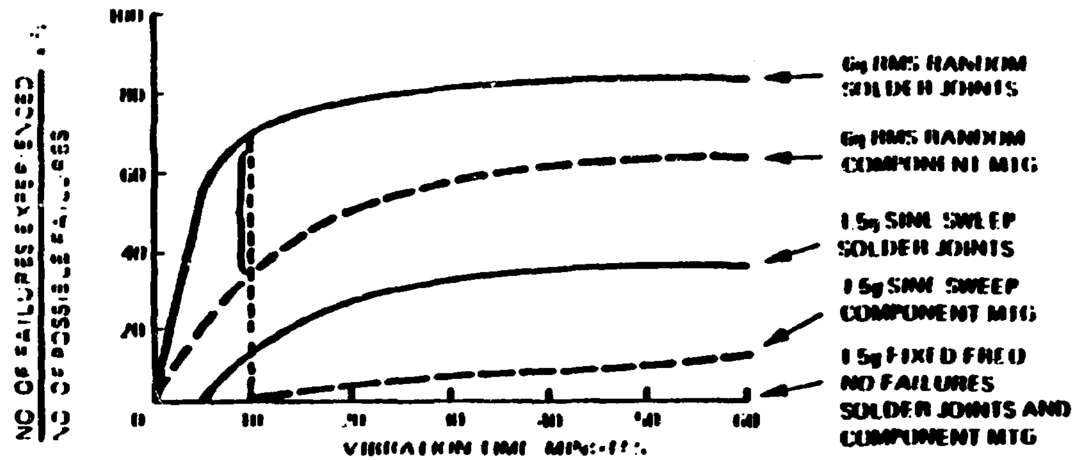
- NAVMAT PUBLISHED P-9492 AND DISTRIBUTED TO 83 TOP CORPORATE OFFICIALS (CHAIRMEN OF BOARDS THROUGH DIVISION VICE PRESIDENTS)
- RESPONSES ENDORSE P-9492 THRUST ENTHUSIASTICALLY
- SOME CONTRACTORS HAVE ALREADY BEEN USING P-9492 TYPE SCREENING AT THEIR OWN EXPENSE BECAUSE OF ITS OVERALL COST IMPROVEMENT
- OTHERS PROPOSE TO SCHEDULE ONTO EXISTING TEST EQUIPMENT, SINCE TEST TIME SO SHORT, IF CONTRACTS REQUIRE
- RESPONSES INDICATE EVEN MORE STRINGENT TESTING OF LATEST COMPLEX ELECTRONIC SYSTEMS, AND TESTING AT LOWER LEVELS OF ASSEMBLY SHOULD BE REQUIRED
- GENUINELY COOPERATIVE, CONSTRUCTIVE RAPPORT DEVELOPING BETWEEN NAVMAT AND INDUSTRY WITH REGARD TO NEED FOR MANUFACTURING IMPROVEMENT

P-9492 THERMAL CYCLING



- NUMBER OF CYCLES BASED ON COMPLEXITY
- RATE OF TEMPERATURE CHANGE UP TO 40°F PER MINUTE
- NO DWELL TIME — REVERSE CYCLE AS SOON AS INTERNAL TEMPERATURES STABILIZE WITHIN 5°F OF CHAMBER TEMPERATURE
- LAST CYCLE TO BE FAILURE-FREE, OTHERWISE CONTINUING CYCLING

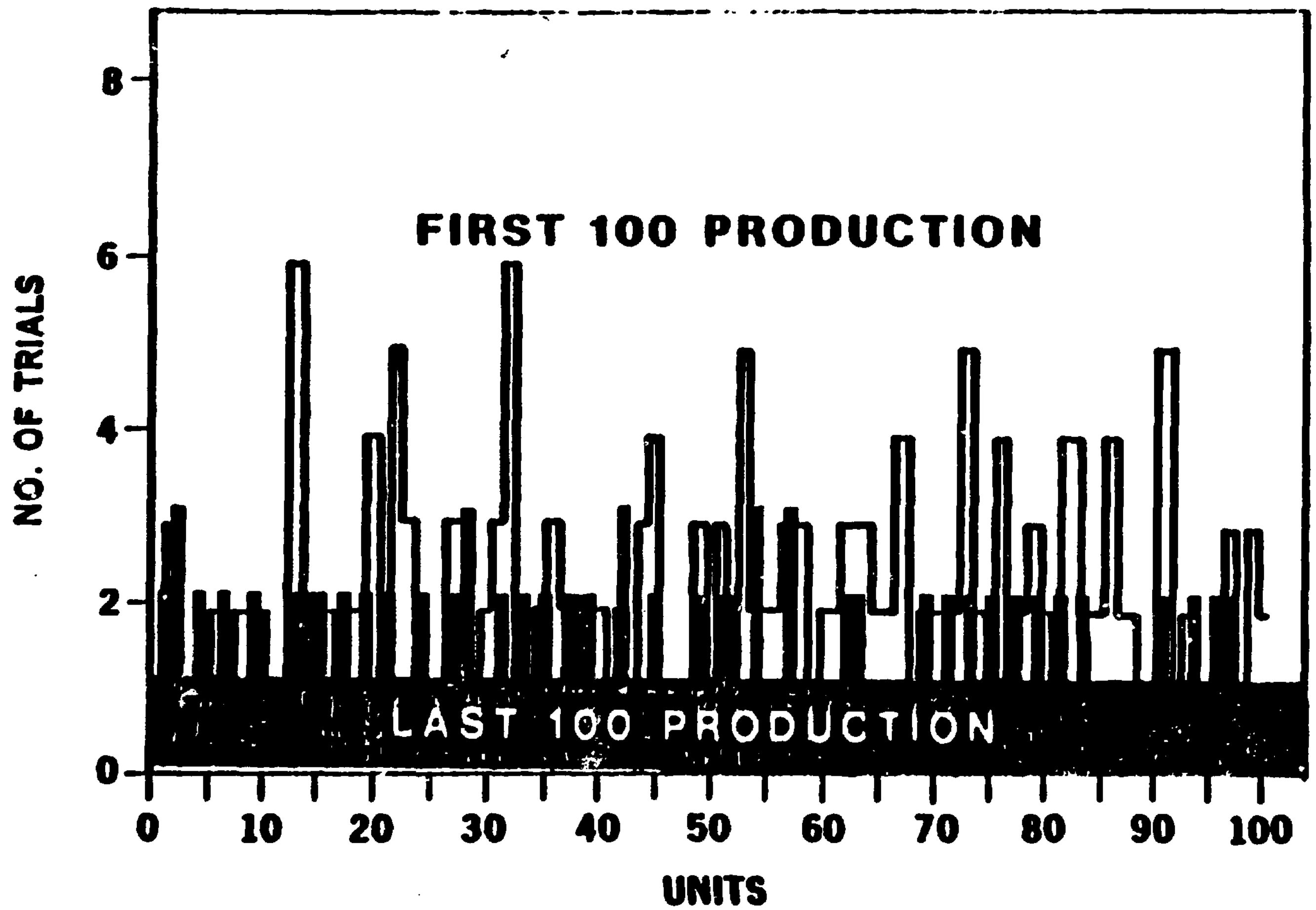
EFFECTIVENESS OF RANDOM VIBRATION



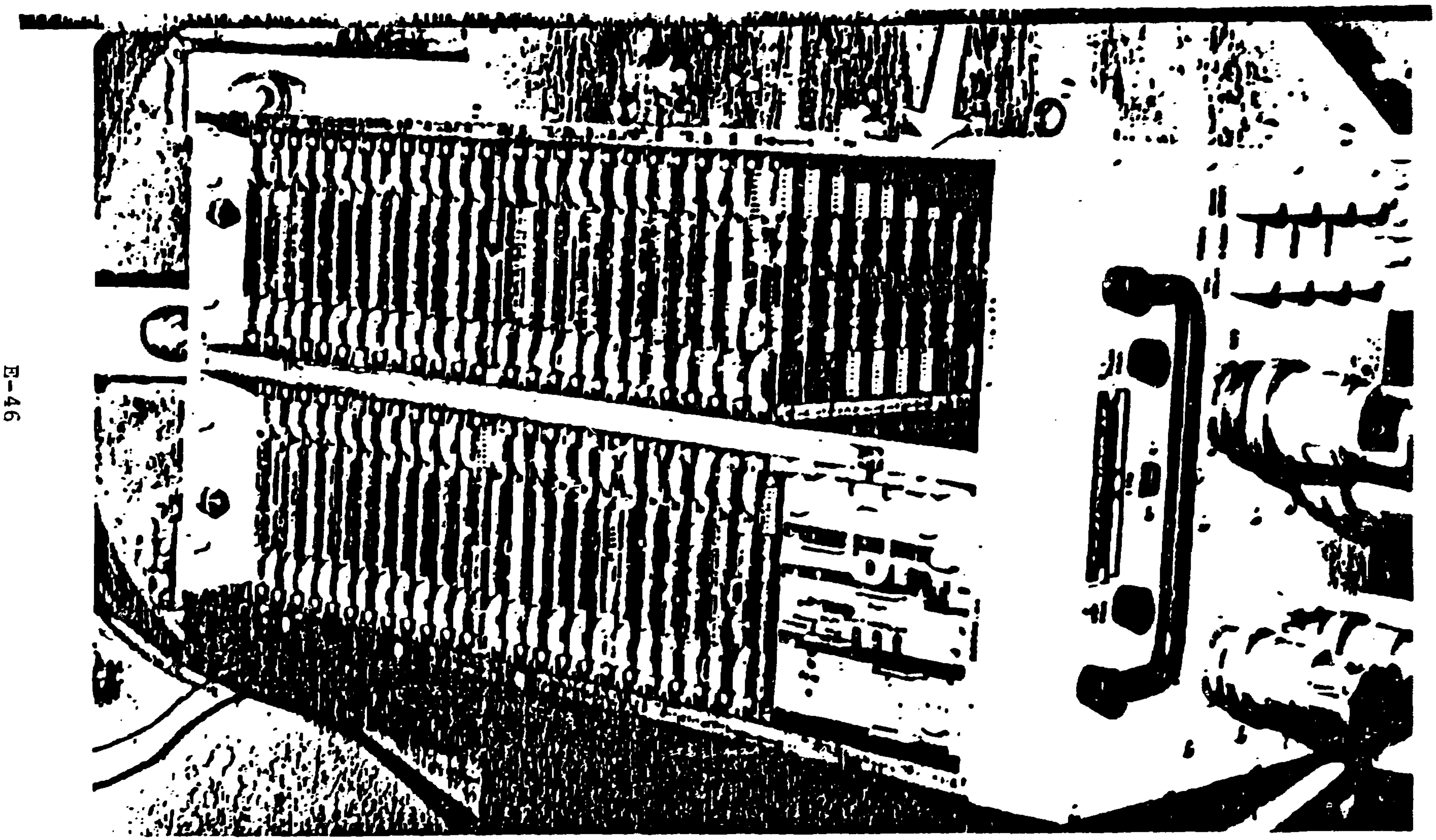
- RANDOM VIBRATION DETECTS HIGHEST PERCENTAGE OF WORKMANSHIP DEFECTS

- ABOUT 50% OF POSSIBLE FAILURES OCCUR IN FIRST 10 MINUTES OF VIBRATION

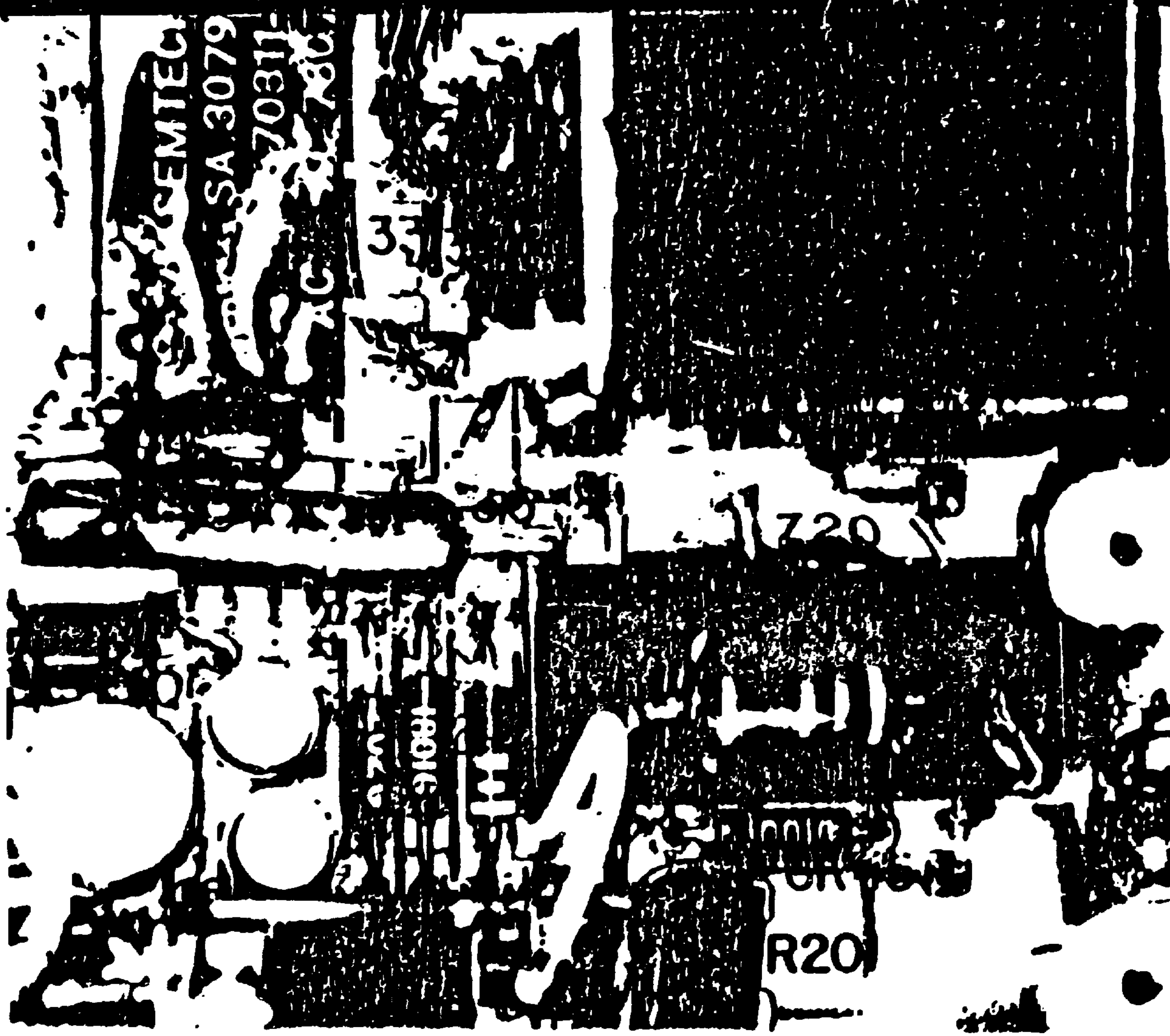
HARPOON SEEKER FINAL ACCEPTANCE TEST



VIDG CONVERTER WITH LOW VOLTAGE POWER SUPPLY REMOVED



RESULTS OF RANDOM VIBRATION



INDUSTRY IN TRANSITION
MANUFACTURING

R 1975 ———————— 1985 G

REPRESENTATIVE CONTRACTORS

	1	2	3	4	5	6	7	8	9	10
POLICY CORPORATE STATEMENT THAT MANUFACTURING QUALITY IS OF PRIME IMPORTANCE	R	R	R	R	R	R	R	R	R	R
ATTITUDES SELF-DISCIPLINE SHOWN IN QUALITY OF MANUFACTURING OPERATIONS	R	Y	R	Y	G	Y	Y	Y	R	G
AWARENESS RELIABILITY IN MANUFACTURING IS 'BUILDING TO PRINT'	G	G	Y	Y	Y	Y	Y	Y	Y	G
STANDARDS MANUFACTURING PRACTICES REFLECT DISCIPLINED QUALITY APPROACH	R	Y	R	Y	G	Y	R	Y	R	G
MOTIVATION FORMAL PROGRAM FOR ACHIEVEMENT AND RECOGNITION	R	R	R	R	R	R	R	R	R	R

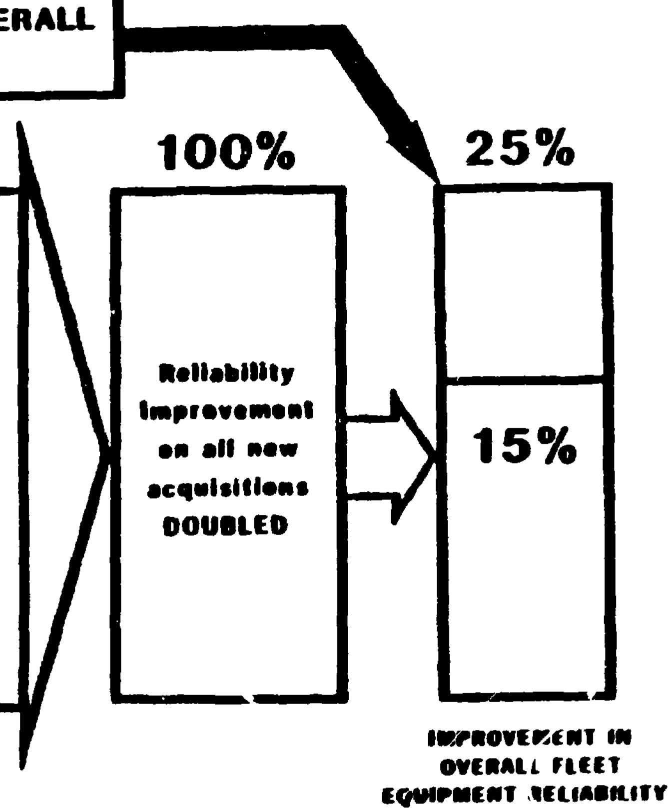
R ACTION REQUIRED   Y IN PROCESS   G ACHIEVED

IMPLEMENTING THE MANDATE
DIFFICULTIES ENCOUNTERED

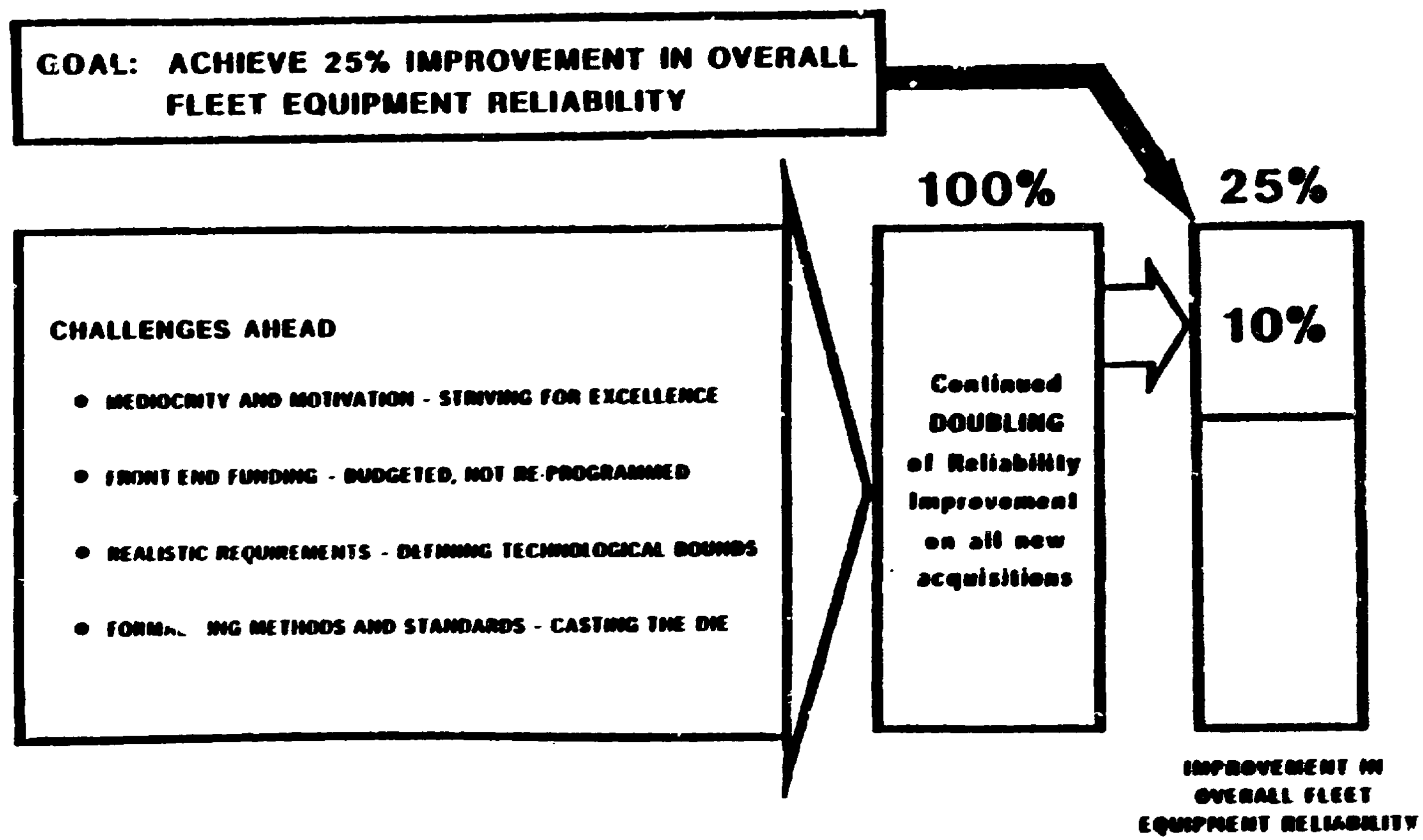
GOAL: ACHIEVE 25% IMPROVEMENT IN OVERALL FLEET EQUIPMENT RELIABILITY

DIFFICULTIES ENCOUNTERED AND OVERCOME

- ESTABLISHING LEADERSHIP - INTEGRATING MANY FACTIONS
- DETERMINING ORGANIZATIONAL LEVELS - INDUSTRY MATCH
- ESTABLISHING CREDIBILITY - TECHNICAL COMMUNITY
- GAINING MANAGEMENT SUPPORT - COMMUNICATION
- VISIBILITY OF PROBLEMS - REVIEWS/PRORs
- PERSONNEL - ATTRACTING EXPERIENCED PEOPLE
- OVERCOMING INERTIA - FIERCE RESISTANCE



ACHIEVING FLEET READINESS
THE CHALLENGES



APPENDIX F:

ROBOTICS AND ARTIFICIAL INTELLIGENCE RELATED PROJECTS LISTING

ROBOTICS
AND
ARTIFICIAL INTELLIGENCE
RELATED PROJECTS
LISTING

The material presented in this listing represents the first step in an attempt to document all robotics and artificial intelligence research and development projects recently completed or currently planned by DOD agencies.

In many cases, the information contained in the descriptions was merely transcribed in abbreviated form from other sources, and no claim to originality is expressed or implied.

Cognizant activities are invited to review and update their respective entries, and forward corrections as well as new additions to the below address.

LCDR Bart Everett
Special Assistant for Robotics
SEA 90M
Naval Sea Systems Command
Washington, DC 20362

(202) 692-6118
A/V 222-6644

PRODUCTION & DISTRIBUTION (81-CONT)

1. Responsible DOD organization: Office of Naval Research
Department of the Navy
Arlington, VA 22217
Attn: Dr. Thomas C. Varley
(202) 696-4313

2. Performing organization: Georgia Institute of Technology
School of Industrial & Systems Engineering
Atlanta, GA 30332
Attn: Mr. H. Donald Ratliff
(404) 894-2307

3. Objective:

4. Approach:

5. Progress: During the past contract period, work was performed in several areas associated with Production and Distribution. Significant progress was made using interactive color graphics computer techniques and human-aid optimization procedures towards advanced concepts in fleet developments, warehouse design, plant layout, and vehicle scheduling procedures.

6. Reference:

AUTONOMOUS UNDERWATER ROBOTS AND VEHICLES

1. Responsible DOD organization: Office of Naval Research
Department of the Navy
Arlington, VA 22217
Attn: A. Meyrowitz
(202) 696-4313

2. Performing organization: Carnegie-Mellon University
The Robotics Institute
Schenley Park
Pittsburgh, PA 15213
Attn: Prof. Raj Reddy

3. Objective: Apply artificial intelligence techniques to the design of autonomous underwater vehicles and robots. Work will be centered on extending the core research areas which are crucial to the creation of intelligent robots: machine vision, reason locomotion, manipulation, and planning.

4. Approach: For the period 1981-1983, research will be centered on furthering the major technological areas essential to autonomous robots: (1) the development of visual and computer reasoning capabilities for real-time navigation and obstacle avoidance; (2) the design of high-power/mass-ratio manipulators to enable strong, dexterous robot arms and hands of reduced size and energy requirements; and (3) the integration of sensor and effector capabilities into a functioning robot.

5. Progress: A) Autonomous Platform: Examining the perception and control problems of autonomous mobile robots in general, using land-mobile vehicles for convenience. Conceived and have largely completed construction of a small but very capable camera equipped rover. Among its innovative features is an omnidirectional drive system using a concentric shaft differential gear wheel assembly of our invention. Three individually steerable and driveable wheel assemblies allow the rover to move forward, sideways, and turn about its own vertical axis in any combination.

   B) Direct Drive Robotic Arm: Demonstration of high-performance in the CMU direct-drive arm (fast response, no backlash, low friction, high repeatibility, and high stiffness), with precise measurement of joint position and joint velocity by means of high-precision (15 bits).

6. Reference: Contract Number N00014-81-K-0503, Work Unit Number NR 610-001.

   The research effort is co-sponsored by Westinghouse Corp., this total initiative is being closely coordinated with ARPA and with emerging robotics interests at NRL, NOSC, NSWC, NSRDC, and SEA 90M.3.

ROBOTICS TECHNOLOGY FOR MILITARY APPLICATIONS

1. Responsible DOD organization: Office of Naval Research
Department of the Navy
Arlington, VA 22217
Attn: A. Meyrowitz
(202) 696-4313

2. Performing organization: Massachusetts Institute of Technology
MIT Artificial Intelligence Laboratory
545 Technology Square
Cambridge, MA 02139
Attn: Prof. Patrick Winston
(617) 253-6218

3. Objective: Apply artificial intelligence techniques to the design of "smart" robots with capabilities of reasoning and vision, spatial planning, sensing, self-locomotion and mobility, and adaptability. Work will be centered both on extending the state of the art and achieving, as an end product, an autonomous hand-eye-brain mechanical system.

4. Approach: The research has the particular goal of accelerating a robotics evolution from a current state of relatively "fixed" automation to the creation of smart mechanical systems with such capabilities as: reasoning and vision, sensing, self-reconfigurable, finger-like dexterity, self-locomotion and mobility, and control of multiple, cooperating robots. An end product goal will be the creation of the world's most advanced hand-eye-brain mechanical system.

5. Progress: The effort is being coordinated with ARPA, and with the current and emerging robotics interests at NRL, NOSC, NSWC, and NSRDC. Such industrial firms as IBM and Unimation Corp. are contributing R&D personnel to the effort; other commercial and university involvements are anticipated. The work is also being closely tied to a related ONR-supported effort at Carnegie-Mellon University.

6. Reference:

MICRO-AUTOMATION: MICRO ROBOTIC ASSEMBLY PROCESSES
(APR 72-DEC 74)

1. Responsible DOD organization: Office of Naval Research
Department of the Navy
Arlington, VA 22217
Attn: M. Denicoff
(202) 696-4303

2. Performing organization: Massachusetts Institute of Technology
Artificial Intelligence Laboratory
Cambridge, MA 02139
Attn: P. Winston
(617) 253-6218

3. Objective: The development of prevision mechanical devices which through the provision of human-like learning, viewing, and manipulative capabilities, are able to supplant or supplement man in performing essential remote control tasks. This project is primarily concerned with the development of a precision miniature hand-eye system, and its operation from a network of computers.

4. Approach: Research in artificial intelligence, focusing on robotics, has the goal of endowing machines with those characteristics that are called 'intelligence' when exhibited by living creatures. These include sensory powers, effector powers, and the power to use a large base both of technical knowledge and of common sense. to make meaningful decisions within the environment. This task is concerned with development of a miniature hand-eye system capable of precision operations to one thousandth of an inch, and its control by a computer network within which simple jobs would be handled locally, while more complex operations or computations would be done on larger centralized machines.

5. Progress: Contractor has designed and built a simple, mini robot arm. Theories have been developed for the creation of an even smaller arm; the new arm to be suitable for tackling an industrial automation problem of electronic assembly, inspection, and repair. Both arms incorporate a force-sensing wrist designed under this project. Experimental studies have been conducted using a PDP-6 computer as the mini computer for control of the arm and force-sensing wrist. Further studies were done exploring computers which offer more capability than the PDP-6 for real-time control in a network environment.

6. Reference:

SUPERVISORY CONTROL FOR TELEOPERATOR AND VEHICLE SYSTEMS
(JUL 81)

1. Responsible DOD organization: Office of Naval Research
Code 455

2. Performing organization: Massachusetts Institute of Technology

Attn: T. B. Sheridan
(617) 253-2228

3. Objective: Investigate operator control performance with Navy teleoperator and vehicle systems employing advanced interactive control methods. The technical goal is to derive models of operator performance and to determine the environmental, task, and control/display factors that most significantly mediate effective control performance.

4. Approach: Theories and normative models are formulated to examine the dynamics of operator-computer collaboration in trading and sharing system control functions. Selection of environmental, task, and control/display variables for this phase of work derives from an analysis of undersea teleoperator and vehicle systems and operations. Relevant sensor communications and computer technologies affecting allocation of control and transfer of information are examined. Laboratory and field experiments are conducted to investigate the effects of control modes and display methods upon operator performance and workload.

5. Progress: Theoretical investigations have produced normative models of supervisory control and have provided a basis for the derivation of principles affecting the allocation of control functions. Laboratory experiments of teleoperator control have demonstrated that the performance benefits of supervisory control vary as a function of task complexity; supervisory control was most beneficial for the more demanding tasks (complex, repetitive manipulations, and movement of the work surface), particularly when performed under degraded feedback conditions (time delays, impoverished video). Current investigations focus on: (a) the formulation of an extensible command language for control input; (b) models of operator monitoring and diagnostic functions; and (c) algorithms for multi-level modes of operator/computer interactive control.

6. Reference:

ROBOT PRODUCTIVITY MULTIPLIERS

1. Responsible DOD organization: Office of Naval Research
Department of the Navy
Arlington, VA 22217
Attn: A. Meyrowitz
(202) 696-4313

2. Performing organization: Massachusetts Institute of Technology
MIT Artificial Intelligence Laboratory
545 Technology Square
Cambridge, MA 02139
Attn: Prof. Patrick Winston

3. Objective: Investigate the design and construction of robots capable of assembling a variety of mechanical devices. Emphasis will be on hand design and operation, touch-sensor signal interpretation, spatial reasoning, and task-oriented language implementation.

4. Approach: This project is designed to address the basic research issues critical in the development and demonstration of an inspection robot capable of verifying three-dimensional shape, the development and demonstration of a vision-equipped, force-sensing, dexterous robot capable of assembling simple mechanical devices, and the transfer of technology and training of people.

5. Progress: Expected milestones in the first year are the creation of a new technology of actuation with emphasis on tendon control, and the development of a theoretical basis for interpreting touch sense information which will make possible the building of a sensor-equipped hand that recognizes objects and determines their orientation. During the second year, a hand will be constructed capable of manipulating a broad class of objects ranging from cylinders and spheres to pipe fittings and electrical connectors, and a high-level, task-oriented language for manipulation will be augmented.

6. Reference:

AUTOMATED SHIP MAINTENANCE
(JUL 77-FEB 82)

1. Responsible DOD organization: Office of Naval Research
Department of the Navy
Arlington, VA 22217
Attn: M. Denicoff
(202) 696-4303

2. Performing organization: Massachusetts Institute of Technology
Artificial Intelligence Laboratory
Cambridge, MA 02139
Attn: P. Winston
(617) 253-6218

3. Objective: This task has the objective of exploiting recent developments in the field of artificial intelligence -- techniques of machine reasoning, vision, and manipulation -- to the goal of exploring potentialities for automating the shipboard maintenance function. More particularly, the objectives include investigation of automation possibilities for machine aiding of engineers/technicians in failure diagnosis and repair; utilization of advanced intelligent systems for on-condition and on-shelf monitoring; and use of manipulation and vision machines for materials movement and spare parts manufacture.

4. Approach: Contractor will utilize the shipboard maintenance environment to develop and test the utility of artificial intelligence techniques to automating weapons maintenance. Contractor plans to examine and extend the application of such recent AI results as: (1) machine understanding and recognition of anomalies related to wiring intricacies of complex circuit designs; (2) machine debugging of equipment failures; (3) use of intelligent support systems for equipment monitoring; and (4) design of advanced maintenance scheduling algorithms.

5. Progress: Progress was made in the fundamental research areas of machine vision and manipulation. Vision results included: (1) the development of methodology for treating specularly reflecting objects such as are likely to be encountered at warehouses and assembly stations, and (2) the design of techniques for dealing with objects with non-uniform surfaces. Manipulation results included: (1) the design of a superior touch sensor which is essential for fine manipulation tasks, and (2) the development of algorithms for avoiding the collision of manipulated objects in free space.

6. Reference:

ROBOTICS CONTROL

1. Responsible DOD organization: Office of Naval Research
   Department of the Navy
   Arlington, VA 22217
   Attn: Dr. A. Meyrowitz
   (202) 696-4302

2. Performing organization: University of Utah
   Salt Lake City, UT
   Attn: Dr. S. Jacobsen
   (801) 581-6499

3. Objective: The development of advanced robots with the capability to perform complex tasks in assembly, inspection, and maintenance requires the solution of many difficult problems, not the least of which is the design of a mechanical hand having the same dexterity as the human hand. The proposed research at the University of Utah will complement the on-going work at MIT in this area by concentrating on subcontrol systems for local management of a multi-jointed hand.

4. Approach: Research in the control of individual fingers will consider the the management of antagonistic tendons and the requirements to produce desired positions. Research in the control of multiple fingers will consider elementary actions (grab, close, twist, etc.) and the requirements for an opposing thumb. The role of sensory information will be studied in determining how grasping functions should be modified in response to tactile information.

5. Progress: An experimental hand, actuated by tendons, has been built.

6. Reference:

DOCUMENTATION OF ROBOTICS CONFERENCE
(3-5 NOV 80)

1. Responsible DOD organization: Office of Naval Research
Department of the Navy
Arlington, VA 22217
Attn: M. Denicoff
(202) 696-4303

2. Performing organization: National Academy of Sciences
2101 Constitution Avenue
Washington, DC 20418
Attn: D. Williams
(202) 389-6635

3. Objective: NAS will provide documentation of the proceedings of the conference on space and military applications of robotics.

4. Approach: Presentations at the conference will be documented by abstracts and copies of slides, viewgraphs, handouts, etc., where applicable.

5. Progress: A booklet of abstracts can be obtained from ONR.

6. Reference:

ROBOTICS SOFTWARE
(APR 82-SEP 84)

1. Responsible DOD organization: Office of Naval Research
Department of the Navy
Arlington, VA 22217
Attn: A. Meyrowitz
(202) 696-4313

2. Performing organization: New York University
Courant Institute of Mathematical Sciences
251 Mercer Street
New York, NY 10012
Attn: Dr. Jack Schwartz

3. Objective: Conduct research in algorithm design and software techniques for robotics.

4. Approach: One goal of this research will be the development of special-purpose robotics languages and very high level languages which include constructs allowing abstract, abbreviated descriptions of tasks, but which also allow for detailed efficiency-oriented treatment of crucial code sections. Such programming tools will be crucial to success in constructing software systems of the expected complexity.

5. Progress: Algorithms for path planning have been developed, and work initiated in automating reasoning about 3-D objects.

6. Reference:

COMPUTER SCHEDULING CAPITAL EQUIPMENT (81-CONT)

1. Responsible DOD organization: Office of Naval Research
Department of the Navy
Arlington, VA 22217
Attn: Dr. Thomas C. Varley
(202) 696-4313

2. Performing organization: University of Florida
Department of Industrial & Systems Engineering
Gainesville, FL 32611
Attn: Dr. Thom J. Hodgson
(904) 392-1464

3. Objective:

4. Approach:

5. Progress: During the past year, research has concentrated on two aspects of scheduling: a computer-aided scheduling system (CASS), and shop flow models. CASS was completed and a variation was developed for NARF-Jacksonville in aircraft induction scheduling. Flow modeling research centered on methods for evaluating various schemes for expressing the interactions within a system. In addition, research was carried out on loading of pallets; i.e., the scheduling of boxes to form a compact load.

6. Reference:

MACROMOLECULAR SYSTEMS/EVOLUTIONARY LEARNING
(JUN 79-SEP 79)

1. Responsible DOD organisation: Office of Naval Research
Department of the Navy
Arlington, VA 22217
Attn: M. Denicoff
(202) 692-4303

2. Performing organisation: Wayne State University, Department of Computer Science
Detroit, MI 48202
Attn: M. Conrad
(315) 577-2477

3. Objective: Study the relation of evolutionary learning by variation and selection to systems of very highly parrallel processors, determine the viability of implementing artificial intelligence systems using variation and selection.

4. Approach: The principal investigator is using the brain as a model for studying chemical and molecular mechanisms underlying natural intelligence. Computational modeling of macromolecular systems have been used to formally demonstrate the capabilities of such systems. Systems as molded are amenable to learning through variation and selection, the principal investigator is currently using computer emulation studies of such designs, with the objective of determining which design features and strategies are essential for evolutionary learning, a specific goal of this work is to consider whether the essential properties necessary for evolutionary learning could be embodied in highly parallel systems of digital components.

5. Progress: Extensive experiments have been performed with the computational model of evolutionary learning. An evolutionary learning algorithm has been developed which is effective for the problems which have been tackled. These problems include simple tasks involving pattern recognition and pattern generation for motor control. A more efficient implementation of the algorithm or an implementation in terms of suitable hardware should allow the solution of significant problems. A firm biochemical foundation for the model has been developed and empirical data (based on the analysis of protein and nucleic acid sequences) which supports the bootstrapping concept of evolutionary learning has been discovered.

6. Reference:

VOICE COMMUNICATION WITH COMPUTERS FOR AUTOMATED DEVICE CONTROL
(FEB 78-JAN 79)

1. Responsible DOD organization: Office of Naval Research
Department of the Navy
Arlington, VA 22217
Attn: M. Denicoff
(202) 692-4303

2. Performing organization: Speech Communications, ONS Research Laboratory
806 W. Adams Boulevard
Los Angeles, CA 90007
Attn: J. E. Shoup
(805) 965-3011

3. Objective: Automated techniques and equipments which will provide speech recognition and speech synthesis would be useful to the Navy. For example, with the proliferation of shipboard and airboard controls, use of voice actuated devices could bring about more rapid control while, at the same time, minimizing the actuation of wrong instruments or controls. Conversely, speech synthesis could bring into being voice warnings of equipment dangers, improper adjustments, and many other similar forms of voice information. This task is attempting to solve some of the problems which are limiting the implementation of automatic speech recognition and automatic speech synthesis equipment.

4. Approach: The approach is to do basic research in speech analysis and synthesis techniques which would lead to automatic derivation of acoustical parameters for automatic recognition and automatic synthesis. Emphasis for the forthcoming year will be a study of what parameters untrained native listeners and trained phoneticians hear when presented with systematically manipulated syllables.

5. Progress: For format variability studies, formant frequencies were measured via the linear prediction method, and the most steady-state 108.8 MS of each token was located by an automatic algorithm.

6. Reference:

DISTRIBUTED ARTIFICIAL INTELLIGENCE

1. Responsible DOD organization: Office of Naval Research
Department of the Navy
Arlington, VA 22217
Attn: Dr. D. Mizell

2. Performing organization: Stanford Research Institute
Artificial Intelligence Group
Menlo Park, CA 94025
Attn: Mr. S. Rosenchein

3. Objective: To develop the scientific basis for design and control of multiple, intelligent machines.

4. Approach: Efforts will be directed towards three goals: (1) developing computational approaches to reasoning about the beliefs of other agents; (2) improving AI planning technology to enable the automatic generation of realistic plans for agents in a distributed environment; and (3) studying ways in which a computer agent might use its model of other agents to plan intelligent communication acts and coordinate its activities with those of the other agents.

These three areas, representing the basic problems in representing and reasoning about the goal-directed actions of multiple intelligent agents, are prerequisite to any solution of the DAI problem.

5. Progress: Have combined the theory of planning with a model of knowledge and belief to derive a system that is able to reason about communicative goals and plan natural language utterances on that basis. The system has been implemented and has proved capable of quite sophisticated reasoning about multi-agent communication. This research is likely to lead to new techniques for controlling multiple robots working cooperatively.

6. Reference: ONR Contract Number N00014-80-C-0296, ONR Work Unit Number NR 610-004.

ADAPTIVE COMPUTER STRATEGIES AND SIMULATION OF ROBOTIC CONTROL
(APR 71-MAR 77)

1. Responsible DOD organization: Office of Naval Research
Department of the Navy
Arlington, VA 22217
Attn: M. Denicoff
(202) 692-4303

2. Performing organization: Stanford Research Institute Artificial Intelligence Group
Menlo Park, CA 94025
Attn: G. J. Agin
(415) 326-6200

3. Objective: The Navy has need for the development of mechanical devices which, through the provision of human-like learning, viewing, and manipulative capabilities, are able to supplant or supplement man in performing essential military tasks in hostile environments. Such devices, realized in one form through the creation of robot mechanisms, will be of value in applications such as deep sea exploration, bomb demolition, and intelligence data collection. This task centers on the development of techniques to enable such devices to adapt to changing situations and environments.

4. Approach: The approach to attain adaptive robotic control strategies will be to develop specific computer learning programs for simulated robotic systems, particular attention will be paid to research on developing a man-machine interactive capability for endowing robot-like devices with perceptual capabilities. Within the context of pictorial data analysis, the contractor will develop interactive strategies for distinguishing between 'figure' and 'background' information. Work will be directed at achieving an automatic scene segmentation of selection capability through the introduction of man-introduced contextual concepts.

5. Progress: A computer-based system capable of recognizing and representing the shape of solid, three-dimensional objects was developed. The initial system was rather rudimentary, so extensions and improvements were made in the recent period; however, an initial attempt at locating a known object by means of data was successful.

6. Reference:

NATURAL LANGUAGE INPUT FOR COMMAND AND CONTROL COMPUTER SYSTEMS (JAN 73-TERMINATED)

1. Responsible DOD organization: Office of Naval Research
   Department of the Navy
   Arlington, VA 22217
   Attn: M. Denicoff
   (202) 696-4303

2. Performing organization: Dartmouth College
   Department of Mathematics
   Hanover, NH 03755
   Attn: L. R. Harris
   (603) 646-2672

3. Objective: The development of normal natural language input to computers and for control of robotic-type devices. This task has the goal of developing generalized techniques for providing natural language and processing to fit various applications.

4. Approach: The approach is to continue research in natural language input and processing by developing techniques that will extend current capabilities in the following three areas: dealing with new linguistic phenomena, performing a wider range of post processing of the data, and interfacing to other data base management system structures.

5. Progress: The techniques developed to date were substantiated by a successful installation of a prototype production within an industrial company. Also, considerable progress was made in many sub-system areas. These included: improvement to the parser, pronoun reference, post processing capability, dealing with more structured data base organizations, and testing the application independence of the techniques. In the past year, a method for properly integrating the spelling checker with the scanner and the parser was developed. A mechanism for merging searching on non-key fields with the DBMS's search capability was realized. Also, a solution for a subtle class of 'how many' questions was designed.

6. Reference:

KNOWLEDGE REPRESENTATION AND ROBOTICS
(AUG 80-CONT)

1. Responsible DOD organization: Office of Naval Research
Department of the Navy
Arlington, VA 22217
Attn: M. Denicoff
(202) 692-4303

2. Performing organization: University of Rochester
Computer Science Department
Rochester, NY 14627
Attn: J. A. Feldman
(716) 275-5671

3. Objective: In most current artificial intelligence research, goals are only implicitly present in the specification of the task. As a consequence, the systems resulting from these efforts have no capability to reason about the problems they are trying to solve. In addition, such 'implicit goal' approaches tend to encourage specific ad hoc solutions that have no hope of being generalized to other problems. The technical objective of this task is to develop a more abstract representation of goals than previously employed.

4. Approach: This research will study the elucidation of flexible, dynamic mechanisms for the exploration of goals and the interpretation of their consequences in knowledge-rich domains. The specific context in which these studies will be conducted include natural language and vision, and robotics.

5. Progress:

6. Reference:

CLUSTERING AND PATTERN RECOGNITION
(JUL 74-MAR 78)

1. Responsible DOD organization: Office of Naval Research
   Naval Research Laboratory
   Washington, DC 20375
   Attn: H. Rabin
   (202) 767-2964

2. Performing organization: Naval Research Laboratory
   Washington, DC 20375
   Attn: J. R. Slagle
   (202) 767-3850

3. Objective: Build a technical foundation for improved methods of automatic computer identification and classification of signals such as radar, sonar, radio, etc. The long-range goal is to use these improved methods to supplement or replace human operators, thus improving performance and/or reducing cost.

4. Approach: Test promising new techniques on a variety of data sets to see how well they perform and what advantages and disadvantages each method possesses. A different technique will be investigated each year according to the following schedule: FY78 sequential pattern recognition; FY79 intrinsic dimensionality; FY80 structural description of patterns; FY81 pattern recognition by the fitting of models; and FY82 automatic model building.

5. Progress: During the past year, work was continued on a package of easily-used computer programs for pattern recognition and clustering, called the NRL pattern recognition package. The project was then terminated and the funds distributed between the robotics project (802-48) and the searcher and the alerter project (802-49).

6. Reference:

ROBOT MANIPULATOR FOR UNDERWATER EXPLORATION
(OCT 77-MAR 80)

1. Responsible DOD organization: Office of Naval Research
Naval Research Laboratory
Washington, DC 20375
Attn: B. Wald
(202) 767-2964

2. Performing organization: Naval Research Laboratory
Washington, DC 20375
Attn: J. K. Dixon
(202) 767-5966

3. Objective: Build a technical foundation for the design of a computer-controlled robot manipulator (arm and hand) for underwater exploration. In particular, to investigate: (1) suitable sensors; (2) computer programs which will integrate sensor information and build up a representation of the environment in the computer memory; (3) high-level programs which will plan actions to carry out the assigned task; and (4) how to provide programs which can compensate for failures.

4. Approach: Identify the alternative solutions to the above problems. Conduct experiments to compare the promising alternatives. A dry robot manipulator will be used and the effects of a wet environment will be simulated as necessary. The programming (artificial intelligence) aspects of the problem will be emphasized rather than the mechanical aspects.

5. Progress: The disassembly program has improved. The robot control system has improved. Several reports and technical papers have been written. Bugs in the computer clock have been fixed. Two waterproof robot hands and a report on sensors have been delivered by a contractor. The disk unit is now connected to the computer. A paper was published. Another paper was accepted for publication. Visits were made to all the major robot laboratories in California. This work is terminated due to lack of funds.

6. Reference:

LASER WELDING AT NIROP

1. Responsible DOD organization: Naval Sea Systems Command
   Washington, DC 20362
   Attn: W. G. Brown
   (202) 692-0298

2. Performing organization: Naval Research Laboratory
   Code 6391
   Washington, DC 20375
   Attn: H. E. Watson
   (202) 767-2622

3. Objective. To reduce the cost of welding heavy sections of mild steels in simple configurations by developing the methods, processing data, and equipment necessary to exploit the capabilities of Laser Welding at the Naval Industrial Reserve Ordnance Plant in Minneapolis, MN.

4. Approach: An initial analysis will identify additional applications to which laser welding may be applied in this project. The criteria are that the structures will be of mild steel up to 1 1/2 inches thick and in configurations which will allow fixturing such that laser welding may be accomplished without elaborate guidance systems. The analysis will also establish the characteristics and specifications of the laser welding equipment. Equipment will then be developed, procured, or adapted as necessary and demonstrated under this project. Equipment development will anticipate and allow for the needs of future MT development projects involving NC control, adaptive control, heavier sections, more demanding materials, etc. During development of the welding equipment, development of weld processing parameters will be carried out using available time on the NRL Laser Equipment. Parameters will be sufficient to allow implementation of the welding processes on a production basis on the specified items at FMC upon completion of the project.

5. Progress:

6. Reference: DNS 00710

ARTICULATING ROBOTICS FOR LASER PROCESS
(FEB 82)

1. Responsible DOD organization: Naval Material Command
Code MAT 0131F

2. Performing organization: Naval Research Laboratory
Material Science & Tech Division
Attn: Mr. H. E. Watson
(202) 767-2622

3. Objective: Develop articulating robotics that will expand the cost effectiveness and utilization of the laser system at NIROP/MPLS.

4. Approach: A robotics system will be developed to operate a laser welder which is being fabricated under contract. Operation of laser welder by robotics will increase productivity and decrease cost of welding operations at NIROP/MPLS.

5. Progress:
(1) Let contract with Avco Everette Research Laboratories to develop requirements of robot forcontrol of Avco laser.
(2) Conducted preliminary negotiations with FMC which will lead to a contract for an abrasive grinding robot.
(3) Conducted comprehensive study of future robotic requirements at FMC, NIROP.

6. Reference:

ARTICULATING ROBOTICS FOR LASER-ASSISTED METAL WORKING

1. Responsible DOD organization: Naval Sea Systems Command
Code SEA 06
Washington, DC 20362
Attn: G. Brown
(202) 692-1919

2. Performing organization: Naval Research Laboratory
Code 6391
Washington, DC 20375
Attn: H. E. Watson
(202) 767-2622

3. Objective: Enhance the Navy's manufacturing capability through the use of Robotics, increasing the flexibility of the laser welding system at the Naval Industrial Reserve Ordinance Plant (NIROP) in Minneapolis, MN. The robot will manipulate the laser beam for welding, cutting, glazing, cladding, and surface heat treatment.

4. Approach: Development of the robotic system will involve the combinations of the best of existing technologies into a single system providing accuracies which are at least an order of magnitude greater than currently exists. The technologies include: robotics, seam tracking, displacement and angular control, and computer and laser technology. Since the work space has been identified as 20 x 20 x 10 feet and the largest part identified as a candidate for laser welding has a diameter of 16 feet, the most practical approach for the structure of the robot is a bridge and trolley configuration. The articulating arm will be supported from the trolley and the laser will be directed through the arm by mirrors located in the joints of the arm and focused on the workpiece.

5. Progress: The project was advertised in the Commerce Business Daily, 27 October 1982. There were approximately 30 responses to the advertisement. Copies of the Request for Proposal were mailed 29 November 1982. A bidders conference was held at NIROP in Minneapolis on 6 January 1983 with 15 companies in attendance. The closing date for proposals was 18 January 1983. Six proposals were received representing 13 companies. The review of the technical proposal will begin immediately.

6. Reference:

ROBOTIC SURFACE PREPARATION AND SURFACE COATINGS SYSTEMS

1. Responsible DOD organization: Naval Ship Systems Engineering Station
   U.S. Naval Base, Bldg. 26
   Attn: T. Galie
   (215) 755-3277

2. Performing organization: Ingalls Shipbuilding Corporation
   Division of Litton Industries
   P.O. Box 149

3. Objective: Conduct Phases I, II, and III and prepare a plan and justification for conducting Phases IV, V, and VI of a multi-phase program to develop two robotic systems:

   a) Surface Preparation System - an industrial robot designed for implementation in shipyard production to clean and prepare the hulls and sub-assemblies of Navy combatants.

   b) Surface Coating System - an industrial robot designed for implementation in shipyard production to paint the hulls and sub-assemblies of Navy combatants.

4. Approach: The contractor shall conduct a structured analysis and preliminary design effort to determine the technical and economic feasibility of pursuing a comprehensive development, test, and evaluation, and implementation program towards the objectives stated in Section 3 above.

   Phase I will consist primarily of the development of the Contractor's Project Plan.

   Phase II will involve: (1) a study of the contractor's current cleaning and painting operations; (2) a synthesis of the complete shipyard operational characteristics for the robotic system(s); (3) development of a structured evaluation procedure including screening criteria and a ranking system for selecting candidate commercially-available servoed manipulators and mobile platforms; (4) a survey of commercially-available servoed manipulators and mobile platforms; and (5) the selection of best choice candidates for future development.

   Phase III will involve: (1) the final selection of the best candidate commercial servoed manipulator and commercial platform; (2) the preliminary engineering design effort; (3) logistic planning; and (4) development of a draft project plan for Phases IV, V, and VI.

5. Progress:

6. Reference:

PROPELLER AUTOMATED WELDING

1. Responsible DOD organization: Naval Sea Systems Command
   Washington, DC 20362
   Attn: R. N. Wells, Jr.
   (202) 692-3581

2. Performing organization: Philadelphia Naval Shipyard
   Philadelphia, PA
   Attn: J. J. Skorko
   (215) 755-3692

3. Objective: Development of a completely automated propeller finishing center. Surface machining is accomplished by the Profiler, an NC milling machine. Optical measurements of dimensional tolerances are accomplished with the Automated Propeller Optical Measuring System (APOMS). The APOMS equipment, in particular, has made possible the In-Process inspections required to obtain feedback for automating the welding and grinding processes. The welding operations are accomplished by the vision-assisted robotic system known as the Propeller Automated Welding System (PAWS). This PAWS system is the newest addition toe the propeller manufacturing center. It is also one of the most advanced robotic systems currently under development for the shipbuilding industry.

4. Approach: The Naval Sea Systems Command has undertaken the development of the PAWS under funding from the Navy Manufacturing Technology/Shipbuilding Technology (MT/ST) Program. The result has been the assembly of a system which uses 3-D vision equipment to guide a welding robot in the performance of seam welding and cladding operations. The 3-D Vision Sensor provides the feedback that is necessary for welding without human intervention when the parts that are to be welded vary in position and geometry. The welding operation is further complicated because of the tendancy to form oxides on the weld puddle surface.

5. Progress: The basic PAWS system, as currently configured, may be used for seam welding, cladding, and inspection purposes. Although experience has, thus far, been gained only on the GMAW process, it is expected that only minimum efforts will be required to extend the system to other processes. To date, the inspecton aspects of the PAWS system are used primarily to reject weld operation when a seam is too narrow or too wide to be properly welded and to control weld parameters for seams in the operating region. In the future, the PAWS inspection capability will be extended to post weld quality reports which will be integrated with APOMS inspection reports. It should be noted that although the PAWS is still under development, it has already demonstrated a wide range of capabilities.

6. Reference: NAVSEA Manufacturing Technology Project DNS 00729.

AUTOMATED PROPELLER OPTICAL MEASUREMENT SYSTEM (APOMS)

1. Responsible DOD organization: Naval Sea Systems Command
Facilities & Equipment Division (SEA 07013)
Washington, DC 20362
Attn: R. Wells
(202) 692-3580

2. Performing organization: Philadelphia Naval Shipyard

Philadelphia, PA 19112
Attn: R. Taseh
(215) 755-3692

3. Objective: To develop a high-speed optical inspection tool capable of automatically measuring ship's propeller surfaces at a lower cost, and provide the designer with sufficient or reliable geometry data to validate the advance propeller design. Inspection of ship's propellers is now performed manually using templates and fairing rods, or with the aid of a pitchometer. Due to the difficulty of obtaining accurate data, only a small percentage of the surface is measured and repeatability is not guaranteed.

4. Approach: Apply optical and software technology already demonstrated in model propeller measurement progress (Navy Contract N00167-79-M-2697 dated 5/31/79) to the measurement of large ship's propellers. Determine optical sensor characteristics and inspection machine geometry parameters that will optimize accuracy and speed of measurement. Define output data format for integration into the Navy QC System. Design, build, and test a prototype propeller measuring system.

5. Progress: Solid Photography, Inc., has under Navy contract N00167-79-M-2697 dated 5/31/79 measurement of model propeller, successfully demonstrated the basic high-speed optical measurement technology required for the inspection of large propellers.

6. Reference: DNS 00718

AUTOMATIC ORBITAL WELDING HEADS

1. Responsible DOD organization: Naval Sea Systems Command
SEA 07032
Washington, DC 20362
Attn: R. Wells
(202) 692-3580

2. Performing organization: Naval Ship Systems Engineering Station
032D
Philadelphia, PA 19112
Attn: L. Noble/M. S. Orysh
(215) 755-3842

3. Objective: Develop automatic welding heads that can be used to weld piping joints where space restrictions are critical: Economizer "U" bend weld joints, economizer element tube to header weld joints and various hydraulic system piping joints, etc. This equipment will be designed for use where the nearest obstruction to the weld joint is 5/8 inch.

4. Approach: Presently, all of the on-board ship welding of piping systems where space restrictions are critical are welded with the manual-shielded metal arc welding process and occasionally with the semi-automatic gas tungsten arc welding process. Due to the space restrictions, the fabrication of these weld joints are time-consuming, prone to repair cycles and, therefore, costly. Ship forces have reported that they experience a high rejection and rework rate when fabricating piping joints described above.

   It is planned to design, manufacture, test orbital welding heads, and evaluate the equipment performance. Welding procedures applicable to these orbital welding heads will be developed and qualified by NAVSSES 032D. The automatic welding heads will be attached to available NAVSEA basic welding power supply unit for testing and for production welding; therefore, no additional power source is required.

5. Progress:

6. Reference:

MOBILE AUTOMATED PROPELLER MEASUREMENT SYSTEM

1. Responsible DOD organization: Naval Sea Systems Command
   SEA 07032
   Washington, DC 20362
   Attn: R. Wells
   (202) 692-3580

2. Performing organization: TBD

3. Objective: The objective of this program is to develop, fabricate, and deliver a mobile optical 3-D propeller measurement system to provide rapid and precision measurement data on ships' propellers at shipyard facilities, both in drydock (on ship) and in the repair shop.

4. Approach: The system to be developed under this project will provide the capability to perform measurements rapidly and accurately using optical 3-D measurement techniques. Measurements will be performed semi-automatically under computer control. The computer will also provide the required data processing and recording functions to enable on-site evaluation of measurement results and deviations from design data. Magnetic tape recording of data will make measurement results available for detailed evaluation by NSRDC, NAVSEA, or other Navy groups. The measurement equipment will be sufficiently mobile such that measurements can be performed either in drydock (propeller mounted on ship) or in the repair shop. The equipment will also be transportable between shipyards.

5. Progress: Proposed.

6. Reference: DNS 869

AUTOMATED SHIP CHECK EQUIPMENT

1. Responsible DOD organization: Naval Sea Systems Command
SEA 07032
Washington, DC 20362
Attn: R. Wells
(202) 692-3580

2. Performing organization: TBD

3. Objective: To obtain a rapid and semi-automated means of obtaining dimensional and configuration data on ships' interiors (ship check data) and of maximizing the usefulness of this data in planning and ships' modifications activities. In addition, the proposed equipment will be useful for automatically performing many measurement tasks such as determination of submarine hull roundness, which are presently difficult and time-consuming to perform.

4. Approach: Ships' survey is now performed manually by survey teams using tape measures and paper and pencil recording techniques. Subsequent conversion of this information to ships' drawings involves time-consuming and error-prone conventional drafting methods. The result is the generation of volumes of drawings which are expensive to generate and store, and often limited in usefulness.

(a) Determine the required parameters of the on-ship optical survey equipment and data recording system, as well as the off-ship CAD-based data processing system which best provides complete and useful ship configuration information.
(b) Establish the optimum means of presenting, manipulating, and storing ships' configuration data to best support ship modification design engineering efforts.

Based on results of (a) and (b) above, design build, and test a prototype automated ships' survey system.

5. Progress: Proposed. However, Robotic Vision Systems, Inc., has successfully demonstrated the ability to gather dimensional data from ship interiors using high-speed optical measuring techniques.

6. Reference: DNS 868

NC MACHINE TAPE VALIDATION

1. Responsible DOD organization: Naval Sea Systems Command
   SEA 62C
   Washington, DC 20362
   Attn: G. Brown
   (202) 692-1939

2. Performing organization: General Electric Company
   Ordnance Systems
   100 Plastics Avenue
   Pittsfield, MA 01201
   Attn: D. A. Citrin
   (413) 494-3830

3. Objective: To provide an NC tape validation system to reduce first-time scrap from complex NC machining, to improve NC machine utilization, to improve cycle time for design changes, and to provide visual aids to assist the machine operators. Current validation of NC tapes is accomplished by cutting a sample part. This is costly and time-consuming, especially when the part to be machined is complex.

4. Approach: A step will be added to the NC drive tape generation process. This step will involve the comparison of the engineering design with the tool patch generated by the NC program. To accomplish this, a three-dimensional representation will be compared analytically to the engineering data base. The outputs of this process will include:

   (a) Pass/fail verification that the final piece will meet the tolarances specified in the engineering data base.

   (b) Visual feedback of NC tool path for tool optimization and interference determination.

5. Progress: Proposed.

6. Reference: DNS 00803

ROBOTIC ABRASIVE CUTTING AT NIROP

1. Responsible DOD organization: Naval Sea Systems Command
SEA 62C5
Washington, DC 20362
Attn: W. G. Brown
(202) 692-1425

2. Performing organization: FMC Corporation
Northern Ordnance Division
4800 E. River Road
Minneapolis, MN 55421
Attn: D. M. Brazys
(612) 571-9201, ext. 2161

3. Objective: Reduce the cost, safety hazards, and production lead times associated with abrasive cutting operations on light and heavy sections of steel and aluminum alloys by the use of robotic technology at Naval Industrial Reserve Ordnance Plant, Minneapolis.

4. Approach: Develop methods, processing data, equipment, and metallurgy necessary to exploit the inherent capabilities of robots in harsh industrial environments, including the use of sensory-mobile robots. Equipment and material science process development would anticipate and allow for the needs of future Manufacturing Technology development projects involving DNC control, adaptive control, material handling of heavier and more complex sections, new alloys, more severe environments, etc. During development of the robotic equipment, development of sensory-mobile robot operating parameters would be determined through quantitative analysis and actual operation of a modified version of state-of-the-art robotic equipment at Battelle-Columbus Laboratories' facilities. Parameters would be sufficient to allow implementation of the sensory-mobile robot fabrication processes on a production basis on the specified items at NIROP, Minneapolis.

5. Progress: Proposed.

6. Reference: DNS 00813

ROBOTIC PIPE FABRICATION WORK CENTER

1. Responsible DOD organization: Naval Sea Systems Command
SEA 0354
Washington, DC 20362
Attn: T. Draschil
(202) 697-2432

2. Performing organization: Newport News Shipbuilding and Dry Dock Company
4101 Washington Avenue
Newport News, VA 23607
Attn: G. J. Snyders
(804) 380-3857

3. Objective: Develop a pipe fabrication work center utilizing robots for marking, cutting, fitting, and welding pipe details.

4. Approach: The current procedures for most ship construction operations are based on manual methods or control. Cutting, grinding, abrasive cleaning, painting, and welding operations, as applied to shipbuilding, although lending themselves to computerized or numerical control methods, have not kept pace with the technological advances in other manufacturing areas. Operations, such as sandblasting and painting, provide hazardous environments for manual operations. Cutting, grinding, and welding operations, although not done on an assembly line basis, are essentially repetitious and require time-consuming set-up and handling.

Develop a work center utilizing robots interfaced with the existing computer-aided design and manufacturing system (CAPDAMS) or a similar system to manufacture pipe details. The system will consist of two robots, a positioner and associated cutting and welding equipment to accomplish most operations in manufacture of pipe detail at one work station, resulting in a decrease in manufacturing time. Improved accuracy and consistency of such a system will also decrease lost time due to rejects and rework.

5. Progress: Proposed only.

6. Reference: JM854

CNC/ROBOTIC STRUCTURAL SHAPE PROCESSING SYSTEM

1. Responsible DOD organization: Naval Sea Systems Command
SEA 05R23
Washington, DC 20362
Attn: T. Draschil
(202) 697-2432

2. Performing organization: Bath Iron Works Corporation
700 Washington Street
Bath, ME 04530
Attn: R. J. Bellonzi
(207) 443-3311, ext. 2709

3. Objective: To develop, install, and demonstrate a prototype CNC/Robotic manufacturing center to accomplish all required cutting and marking of steel and aluminum ship structural shapes (angles, tees, channels, etc.).

4. Approach: Production of ship structural components (longitudinal stiffeners, etc.) is a documented low technology, highly labor intensive operation. Individual pieces are manually defined, marked and cut with hand-held flame torches, and inefficiently-handled multiple times.

Basic feasibility of an industrial robot (1) cutting 3-D with a plasma torch; (2) achieving repeatable accuracy/positioning vs. raw material up to 50' long; and (3) being efficiently programmed and controlled in a CNC mode will be determined through a related FY81, NAVMAT-sponsored R&D effort at BIW. This project will implement and demonstrate the first actual application of this new technology.

5. Progress:

6. Reference: DNS 50001

ROBOTIC PRODUCTION/ASSEMBLY OF BLASTING CAPS

1. Responsible DOD organization: Naval Sea Systems Command
   Manufacturing Technology Office
   Code 05R2
   Washington, DC 20362
   Attn: H. B. Byron
   (202) 697-2432

2. Performing organization: TBD

3. Objective: To develop and implement robotic equipment and techniques for the production of RF&E (radio frequency and electrostatic) resistant blasting caps, squibs, and detonators, in order to improve productivity, increase safety, and lower unit prices. Current issue blasting caps and squibs are not protected against stray RF energy and do not contain electrostatic protection. The likelihood of accidents from either source is high and service personnel are prohibited from using these devices in certain locations.

4. Approach: New RF&E resistant blasting caps and squibs designed to resolve these problems have been produced in limited quantities and are currently undergoing HERO (Hazards of Electro-Magnetic Radiation to Ordnance) certification and safety testing. The current price of the units is $14.90. The cost is high because of hand-winding required in the ferrite choke, hand-welding of very small parts, and critical operations, such as manual remote control positioning of parts in the blasting cap body.

   Semi-automatic equipment and robotic processes will be developed which are compatible with design requirements and will produce and assemble the parts. The first effort will be to lower the cost of winding the ferrite choke and packaging it with other components into a pre-assembled unit ready for insertion into the blasting cap. The second effort will be to develop equipment to assemble the final configuration of the blasting cap. Both of these efforts will be accomplished by designing, building, and testing production scale semi-automatic equipment. Robotic equipment is necessary due to the danger associated with assembly of energetic materials. A two-year effort is anticipated.

5. Progress: Proposed.

6. Reference:

LASER CONTROLS TO UPDATE WORN MACHINE TOOLS

1. Responsible DOD organization: Naval Sea Systems Command
SEA 03542
Washington, DC 20362
Attn: H. B. Byron
(202) 697-2432

2. Performing organization: FMC Corporation
Northern Ordnance Division
4800 East River Road
Minneapolis, MN 55421
Attn: R. P. Veldt
(612) 560-9201, ext. 572

3. Objective: To improve precision machining capability of worn machine tools by means of a laser interferometer tool-position indicator.

4. Approach: NAVSEA has several hundred elephant machine tools (vertical and horizontal boring machines: jig bores, planers, slotters, etc.) that are used in Navy facilities and/or contractor-owned or operated facilities to manufacture and/or overhaul naval ordnance and ship propulsion equipment. Most of these tools are circa 1941-45 and form the largest percentage of the Navy's large machining industrial base. Lucas Company has built and sold several new precision machine tools equipped with an LI measurement system in addition to their standard digital controller. However, there has been no known retrofitting of older worn machine tools with LI systems. This project would utilize commercially available LIs to restore accurate/ precision machining capability to these elephant tools, enable operators to compensate for machine wear, and considerably reduce machine set-up time.

   Contractor would develop specifications and procure a 4 axis (one X, two Y, one Z) LI measurement system. Install the system on a Navy-owned machine tool at Naval Ordnance Station, Louisville, KY.

5. Progress: Proposed. However, NAVSEA 06G2 has been working with the National Bureau of Standards (NBS) to develop a low-cost laser interferometer with a projected cost of 1K each - which looks promising for some machine tool applications.

6. Reference: DNS 00658

OBSOLETE PARTS REPLICATION

1. Responsible DOD organization: Naval Sea Systems Command
SEA 07032
Washington, DC 20362
Attn: R. Wells
(202) 692-3580

2. Performing organization: TBD

3. Objective: To significantly reduce the time and cost associated with the manufacture of failed obsolete parts through the use of optical 3-D inspection of the original part and conversion of the part data into numerical control machining instructions in a CAD/CAM system.

4. Approach: Present methodology used in replication of failed parts for which drawings no longer exist requires laborious manual measurement of the original part, creation of a part drawing based upon these measurements, and subsequent machining of a new part from this drawing. The overall process is time-consuming and costly, and requires increasing, unavailable, high-skilled labor.

The emerging capability of automated machining based upon CAD/CAM-generated machining instructions provides the potential for automated part replication. The full realization of this potential is predicated on the ability to efficiently create a mathematical model of the original part in the CAD/CAM system. The proposed system provides this model by digitizing the 3-D surface contours of the original part using automated optical 3-D measurement techniques and, with the interactive aid of the CAD/CAM operator, reduce the raw data base thus created to a simplified geometric model of the original part. The proposed system makes maximum use of hardware which presently exists in Navy inventory or is being developed for the Navy under other contracts.

5. Progress: Proposed. The APOMS (Automated Propeller Optical Measurement System), which will provide the part measurement capability for the proposed system, is presently under development by RVSI under Navy contract number N00140-80-C-0892.

6 Reference: S70004

ADAPTIVE SEAM AUTOMATED WELDING SYSTEM

1. Responsible DOD organization: Naval Sea Systems Command
   SEA 07032
   Washington, DC 20362
   Attn: R. Wells
   (202) 692-3580

2. Performing organization: Philadelphia Naval Shipyard

   Philadelphia, PA 19112
   TBD

3. Objective: To develop, fabricate, and demonstrate an adaptive seam welding system which will significantly enhance the productivity and weld quality associated with automated (robotically manipulated) welding systems.

4. Approach: Under this program, a welding "end effector" for a robotic manipulator will be developed which will provide the adaptive capabilities deficient in present automated welding systems. The "end effector" will consist of a weld torch with self-contained vernier positioning capability sufficient to compensate for the minor seam variations cited above. Vernier control will be provided by a 3-D vision capability on the end effector which will sense the seam variations in advance of the instantaneous torch position and thereby dynamically adjust the torch position to follow seam center, optimize weave patterns, and maintain correct arc length. In addition, a sensor will be provided to observe the weld characteristics behind the torch position to sense seam "fill." Data from this sensor will be used to dynamically control weld system parameters for optimal maintenance of seam fill. Vision data processing and control functions will be provided by a mini-computer.

5. Progress: Proposed. NAVSEA is under contract with Robotic Vision Systems, Inc., to provide automated seam welding of ships' propellers using a robotic weld torch manipulator and 3-D vision for seam position location prior to welding. The adaptive seam welding concept to be developed under the program herein is an extension of these efforts to the general seam welding problems experienced by the Navy.

6. Reference: S70000

AUTOMATED FUSION WELD INSPECTION
(JAN 81-SEP 83)

1. Responsible DOD organization: Naval Sea Systems Command
   Materials and Mechanics Division
   Washington, DC 20362
   Attn: H. N. Byron
   (202) 692-2432

2. Performing organization: Naval Ocean Systems Center
   Electronics Engineering and Sciences Department
   San Diego, CA 92152
   Attn: J. S. Markall
   (714) 225-7136

3. Objective: To develop and implement into the cruise missile production line an automated fusion weld inspection station that will reduce the recurring time associated with the present manual operation and increase throughput of missile body sections.

4. Approach: The technical objective of this effort will be met by mechanizing and automating the present manual inspection operation utilizing an industrial robot. The robot will position the x-ray source and a motorized assembly cart will position the cruise missile body sections. There will be two systems implemented into production. The second system will include a computer-controlled film manipulator and filmless inspection equipment (i.e., imaging system).

5. Progress: None. New project.

6. Reference:

REMOTE VISION SYSTEM FOR ROBOT PROGRAMMING

1. Responsible DOD organization: Naval Material Command

   Washington, DC 20360
   Attn: J. McInnis
   (AV) 222-6850

2. Performing organization: Naval Ocean Systems Center

   San Diego, CA 92152
   Attn: Dr. A. Gordon
   (AV) 933-6686

3. Objective: To establish the generic technology capability to integrate the elements of an automated ship welding system. Specifically to design, develop, fabricate, and test a remote vision system and integrate it with a robotic ship welding system. This integrated system will be used to demonstrate robotic shipyard welding under remote control. Such a capability will result in significant cost reduction in the fabrication of ships.

4. Approach: Develop the ability to remotely guide a robot arm under the control of a human operator located outside of the arm's operating envelope. The control portion of this capability already exists in the form of remote controller boxes supplied by the robot vendors or, at a more advanced level, through remote joystick controllers. What is currently lacking is a precise visual feedback system to allow a remote operator to visualize the end effector in relation to the workpiece and desired spatial path. Similar problems have been encountered in the use of remote manipulators underwater. These problems have been solved at NOSC through the use of in-house designed remote stereoscopic television systems. It is proposed to adapt this technology and integrate such a vision system with a robotic arm.

   The capability to be developed during this program will be introduced in a series of phased demonstrations. Immediately after laboratory development, the remote vision system will be integrated with a Cincinatti Millicron T-3 arm and the SRI International joystick controllers. The system's welding capability will be evaluated under laboratory conditions. Results from this evaluation will be used for a final modification [illegible] opt[illegible] system parameters, if necessary. Model shipyard testing, perhaps in conjunction with a manufacturing technology IR&D effort, will evaluate the remote vision capability in a shipyard production environment. Complete specification and documentation of this system will then allow its final implementation as a production system.

5. Progress:

6. Reference: DNS 50029

KNOWLEDGE-BASED WELDING SYSTEM FOR SHIP CONSTRUCTION

1. Responsible DOD organization: Naval Material Command

   Washington, DC 20360
   Attn: J. McInnis
   (AV) 222-6850

2. Performing organization: Naval Ocean Systems Center

   San Diego, CA 92152
   Attn: S. Harmon
   (AV) 933-2083

3. Objective: To establish generic processing technology necessary to integrate the elements of an automated, low cost ship welding system. Specifically, the sensory information signal interpolation capability for adaptive control of automated ship welding will be established and integrated with a total weld system.

4. Approach: Concepts for robot vision and robot control for welding operations are presently being explored by several research groups. These concepts can be integrated through a knowledge-based planned system. Robot vision systems transform raw signal input into a more refined form of information. The most advanced vision systems can deliver descriptions of observed scenes in terms of identity, position, and orientation of major surfaces of a given scene. This information must then be integrated with other sensor information including human advice and with the desired goals for the welding operation to produce an assessment of the specific actions required of the robot to accomplish the task. This can be done using inference network reasoning techniques which have been developed for and demonstrated in expert systems for various applications.

5. Progress: The knowledge management system will be implemented on a high-performance microprocessor in a language such as Pascal, ADA, LISP, or PROLOG depending upon availability. A welding robot will be acquired from a commercial source and implemented as the beginning of the pilot system. The sensor and control project developments will be integrated with the knowledge management system and welding robot. Specific practical welding tasks will be chosen and demonstrated in a ship production mode.

6. Reference: DNS 50030

SUPERVISORY CONTROL OF TELEOPERATOR AND VEHICLE SYSTEMS (FEB 82)

1. Responsible DOD organization: Office of Naval Research
Psychological Sciences Division

2. Performing organization: Naval Ocean Systems Center
Ocean Technology Department
Attn: Mr. P. J. Heckman, Jr.
(714) 225-6686

3. Objective: Provide technical support for an ONR-sponsored research program being conducted at the MIT Man-Machine Systems Laboratory on computer-aided supervisory control of teleoperators and vehicle systems. The goal is to test models of operator performance and to demonstrate supervisory control concepts in a research testbed for advanced underwater teleoperator systems at NOSC.

4. Approach: Based upon theories of semi-autonomous control and models of operator performance developed under ONR-sponsored research at MIT, design concepts are formulated for computer-aided supervisory control of an advanced untethered submersible and dexterous remote manipulator. Distributed control algorithms, computer software, and operator-computer interfaces are designed and implemented in a research testbed. In collaboration with the MIT research team, investigations are conducted in the laboratory and under field conditions to validate models of operator performance, test theories of supervisory control and demonstrate computer-aided control concepts using the research testbed for an advanced untethered submersible.

5. Progress: Under IR/IED sponsorship, NOSC has completed design, development, and fabrication of an advanced computer-controlled underwater manipulator. In cooperation with MIT, distributed control algorithms, computer software, and operator computer interfaces have been designed. The software has been integrated INTOAN LSI 11/23 computer and preliminary supervisory-controlled experiments have been completed in the air.

6. Reference:

ADVANCED TECHNOLOGY APPLIED TO MSNAP
(FEB 82)

1. Responsible DOD organization: Naval Sea Systems Command
PMS 377

Attn: Larry Benem

2. Performing organization: Naval Ocean Systems Center
Environmental Sciences Department
Attn: Dr. R. L. Pepper
(808) 254-4409

3. Objective: Systematically investigate and identify the technology advances which are currently available to enhance fleet logistics support missions.

4. Approach: Develop an integrated task plan to explore the utilization of merchantships for supply, troop transport, hospital services, and the emergency utilization of small auxiliaries. Systematically identify the tradeoff between capital intensive and labor intensive components of MSNAP equipment. Determine potential improvements in reliability and reduction in quality and quantity of manpower costs as a result of applying automation and artificial intelligence in these areas. Initiate the development of a merchant ship crew augmentation system with emphasis on the application of research findings upon minimum space utilization and computer-controlled ration preparation and delivery.

5. Progress: Task plan for technology support for UNREP mission has been developed. Evaluation model and performance criteria are in initial design stage. Information collection and observation of UNREP manpower and training problem areas have begun.

6. Reference:

ADVANCED TECHNOLOGY TO AID FLEET READINESS
(FEB 82)

1. Responsible DOD organization: Naval Sea Systems Command

2. Performing organization: Naval Ocean Systems Center
Environmental Sciences Department
Attn: Dr. R. L. Pepper
(808) 254-4409

3. Objective: Prepare concepts for incorporating artificial intelligence (AI), teleoperator, and robotic technology in the fleet logistics program to minimize ship size.

4. Approach: Survey and incorporate artificial intelligence concepts with ongoing teleoperator technology efforts to establish directions and concepts for human supervision of groups of teleoperator machines for logistics tasks such as maintenance, horizontal, and vertical movement of cargo, and food handling and preparation.

5. Progress:
(1) AI survey initiated to determine potential utilization in logistics mission. Report in preparation.
(2) Survey of research literature for personnel support subsystems in process. Preliminary report of state-of-industry equipment in food handling and preparation in draft form.
(3) Visual display requirements analysis on heavy lift and vertical material handling equipment initiated.

6. Reference:

AUTOMATED FUSION WELD INSPECTION
(FEB 82)

1. Responsible DOD organization: Naval Sea Systems Command
   Materials & Mechanics Division

2. Performing organization: Naval Ocean Systems Center
   Electronics Engineering & Sciences Dept.
   Attn: J. S. Markall
   (714) 225-7136

3. Objective: To develop and implement into the cruise missile production line an automated fusion weld inspection station that will reduce the recurring time associated with the present manual operation and increase throughput of missile body sections.

4. Approach: The technical objective of this effort will be met by mechanizing and automating the present manual inspection operation utilizing an industrial robot. The robot will position the x-ray source and a motorized assembly cart will position the cruise missile body sections.

5. Progress: A contractor's proposal package has been reviewed and forwarded to NRCO for processing.

6. Reference:

A DEMONSTRATION OF AUTONOMOUS ROBOTICS TECHNOLOGY
(OCT 80-SEP 81)

1. Responsible DOD organization: Naval Material Command
Director of Laboratory Programs
Washington, DC 20360
Attn: Dr. H. L. Blood
(714) 225-7275

2. Performing organization: Naval Ocean Systems Center
Systems Department
San Diego, CA 92152
Attn: S. Y. Harmon
(714) 225-2083

3. Objective: Develop and demonstrate concepts which will permit the realization of completely autonomous systems which can function in complex unstructured task environments.

4. Approach: Software will be designed for the computer control system of an existing, remotely controlled submersible vehicle to enable that vehicle to perform an ocean search task autonomously in an actual ocean environment. The software design will be approached through an adaptation of existing system software design methodology. This methodology involves the systematic definition of the necessary components of the robot's knowledge structure as well as the coupling between those components. These concepts integrate major ideas from the technical disciplines by automatic control theory, artificial intelligence, computer communications, and modern real-time operating system design.

5. Progress: None. New project.

6. Reference:

ARTIFICIAL INTELLIGENCE FOR NAVAL APPLICATIONS
(FEB 82-CONT)

1. Responsible DOD organization: Naval Surface Weapons Center

2. Performing organization: Naval Surface Weapons Center

Attn: J. Scarzello
(202) 394-2467

3. Objective: Explore and develop artificial intelligence technology and concepts and apply them to specific Navy problems.

4. Approach: Eight research tasks in the areas of fundamental limits, natural language understanding, AI for pattern recognition for target identification, and classification are being pursued for specific personalized testbed areas in order to develop the AI technology involved.

5. Progress: This is a new start.

6. Reference:

COMPUTER-AIDED MANUFACTURING
(AUG 81-CONT)

1. Responsible DOD organization: Naval Sea Systems Command
SEA 03R23

2. Performing organization: Naval Surface Weapons Center

Attn: T. R. McKnight
(202) 394-3256

3. Objective: Provide technical expertise and management services in the identification and application of technology to improve the acquisition of Navy ships systems.

4. Approach: Investigate current state-of-the-art in robotics technology, interactive graphics technology. Automated inspection techniques, automated materials handling, signal processing and computer-aided fabrication techniques.

5. Progress: Interim reports have been presented to NAVSEA. Final report is being completed.

6. Reference:

HYDRAULIC ROBOT (HT(3))
(FEB 82-CONT)

1. Responsible DOD organization: Naval Surface Weapons Center

2. Performing organization: Cincinnati Milacron Mark Company

Attn: S. Dhingra
(201) 560-1800

3. Objective: Provide the Naval Surface Weapons Center with an HT(3) robot. This work supports agency accession DN185116.

4. Approach: Deliver to NSWC.

5. Progress: Robot to be delivered no later than March 1983.

6. Reference:

SHIPBOARD ROBOTICS FOR CREW REDUCTION AND SYSTEM CONTROL
(JUL 73-JUN 74)

1. Responsible DOD organization: Naval Ship R&D Center
Bethesda, MD 20034
Attn: A. Powell
(202) 227-1628

2. Performing organization: Naval Ship R&D Center
Computation & Math Department
Bethesda, MD 20034
Attn: J. Carlberg
(202) 227-1889

3. Objective: To investigate and evaluate the employment of artificial intelligence, automation, robotics, and computer-related control techniques aboard ships to facilitate and promote effective crew reduction and/or improve and enhance ship performance and capabilities.

4. Approach: Maintain and extend knowledge of existing theories of pattern recognition and artificial intelligence techniques. Visit and maintain technical exchange with DOD contractors (S.R.I.; M.I.T.) involved in robotics and artificial intelligence research and development. Establish technical contact with the fleet through the NSRDC fleet liaison officer and maintain liaison through extensive onboard visits and acquaintance with training and operating procedures. Establish and maintain cooperation with project office for ship automation and reduced manning (Propulsion and Auxiliary Systems Department, Code 27, NSRDC, Annapolis) to expose theoretical developments in A.I. to real applications. Select a particular operational functional, such as enemy avoidance, underwater scene sensing or description, or special automated control systems, as an area where further research will bear tangible results.

5. Progress: (April-June 1974) Report being typed, includes. (1) organizational summary; (2) simulation specifications relating deg (destroyer escort) mission areas, watch organization, personnel lists to task performance, and (3) recommendations for further work in manning reduction for administration, equipment management, and damage control. Work to continue under NAVSEA 6.1 funds.

6. Reference:

NSRDC ROBOTICS PROGRAM

1. Responsible DOD organization: David Taylor Naval Ship Research and Development Center
Bethesda, MD 20084
Attn: Mr. J. Sheehan
(202) 227-1285

2. Performing organization: David Taylor Naval Ship Research and Development Center
Bethesda, MD 20084
Attn: Mr. R. Jenkins
(202) 227-1363

3. Objective: Implement an NSRDC robotics program to focus on the establishment of a robotics technology base to support Navy interests in robotics technology, ranging from original manufacture to operation, repair, and maintenance.

4. Approach: Advanced technological developments in welding, non-destructive testing, and surface preparation were studied and the feasibility of using robotics to implement these technologies in shipbuilding was evaluated. At the same time, the economic feasibility of proposed robotics work-stations was considered to determine the return on investment when manual methods are replaced by robotic systems. Each area was found to offer the possibility either of greatly increased productivity or decreased hazards to shipyard workers.

5. Progress: The various robotic application areas have been described and specific recommendations for implementing such systems have been documented. The areas include electron beam and laser beam welding of submarine hull wing frame and pressure hulls, narrow gap welding of submarine pressure hulls and carrier decks, assembly of inner bottom structural sub-assembly modules, painting of hulls, and removal of paint/rust/scale from hulls. Significant cost savings were discovered in most of these areas.

Support was provided to the Naval Sea Systems Command in developing, processing, and monitoring two contracts specifically intended to introduce robotics into the ship-building industry. The first deals with the construction and installation of a production robotic arc-welding station at Todd Shipyard. In addition to other devices, the robot is to be fitted with a vision sensor to provide real-time adaptive control of the robot. The second contract deals with the development and installation of a structural shape-processing robot at Bath Iron Works. Efforts are being made to link this robot directly to a digital data base defining the ship structure.

6. Reference: Robotic Automation in Advanced Navy Ship Construction/Repair, DTNSRDC-82/44, July 1982.

ROBOTICS APPLICATIONS IN NAVAL MAINTENANCE

1. Responsible DOD organization: David Taylor Naval Ship Research and Development Center
   Bethesda, MD 20084
   Attn: Mr. J. Sheehan
   (202) 227-1285

2. Performing organization: David Taylor Naval Ship Research and Development Center
   Bethesda, MD 20084
   Attn: Mr. R. Johnson
   (202) 227-1058

3. Objective: Identify applications for employment of currently available robotics machinery, develop, and install prototypes in the most promising applications and identify new developments of benefit to naval aviation logistics and maintenance functions.

4. Approach: DTNSRDC Computation, Mathematics and Logistics Department Program has focused on the organizational ("O") and intermediate ("I") levels of naval air maintenance. The objectives of the project are: (1) to identify potential applications; (2) to estimate the benefits of robotic use; and (3) to identify particularly useful robotic developments for air maintenance tasks. Achieving these objectives would provide valuable insight for Navy planning of robotic installation and research projects. Conceptual applications and general robotic designs will focus attention on particular Navy requirements (of known or estimate value). In the course of the project, a valuable in-house technology and technical robotic expertise base will have been created.

5. Progress: The first year of this multi-year effort, begun in FY82, concentrated on characterizing the existing robotics technology. A survey of current robotic technology indicated that the robotic areas receiving major R&D efforts include increasing the range of robot sensory capabilities in vision, force and tactile sensing, and creating robotic systems which can be more easily programmed and driven from external computer systems. Other generic areas of robot capabilities receiving less attention include standardization of control languages, electrical and mechanical inter-connections, methods of robot calibration, and issues related to robot mobility.

   Project efforts in FY83 will focus on naval air maintenance tasks and the relationship of these tasks to the objectives. Near-term robotic task applications will be identified as candidates for follow-on development.

6. Reference:

ROBOTICS APPLICATIONS IN NAVAL MAINTENANCE

1. Responsible DOD organization: David Taylor Naval Ship Research and Development Center
Bethesda, MD 20084
Attn: Mr. J. Sheehan
(202) 227-1285

2. Performing organization: David Taylor Naval Ship Research and Development Center
Bethesda, MD 20084
Attn: Mr. R. Johnson
(202) 227-1058

3. Objective: Identify applications for employment of currently available robotics machinery, develop, and install prototypes in the most promising applications and identify new developments of benefit to naval aviation logistics and maintenance functions.

4. Approach: DTNSRDC Computation, Mathematics and Logistics Department Program has focused on the organizational ("O") and intermediate ("I") levels of naval air maintenance. The objectives of the project are: (1) to identify potential applications; (2) to estimate the benefits of robotic use; and (3) to identify particularly useful robotic developments for air maintenance tasks. Achieving these objectives would provide valuable insight for Navy planning of robotic installation and research projects. Conceptual applications and general robotic designs will focus attention on particular Navy requirements (of known or estimate value). In the course of the project, a valuable in-house technology and technical robotic expertise base will have been created.

5. Progress: The first year of this multi-year effort, begun in FY82, concentrated on characterizing the existing robotics technology. A survey of current robotic technology indicated that the robotic areas receiving major R&D efforts include increasing the range of robot sensory capabilities in vision, force and tactile sensing, and creating robotic systems which can be more easily programmed and driven from external computer systems. Other generic areas of robot capabilities receiving less attention include standardization of control languages, electrical and mechanical inter-connections, methods of robot calibration, and issues related to robot mobility.

   Project efforts in FY83 will focus on naval air maintenance tasks and the relationship of these tasks to the objectives. Near-term robotic task applications will be identified as candidates for follow-on development.

6. Reference:

THE EXTENSION OF MAN'S UNDERWATER-WORK CAPABILITY THROUGH ACOUSTIC AND MANIPULATOR TECHNOLOGIES
(OCT 77-OCT 81)

1. Responsible DOD organization: Naval Medical Research and Development Command
National Naval Medical Center
Bethesda, MD 20014
Attn: C. E. Brodine
(202) 295-1453

2. Performing organization: Naval Medical Research Institute
Behavioral Science Department
Bethesda, MD 20014
Attn: W. W. Banks
(202) 295-1792

3. Objective: The purpose of this study is: (1) to define those variables that affect operator performance when the operator is required to interact with manipulator and imaging equipment; (2) to quantify the impact of these variables and take measures; (3) to develop a performance prediction model based on these variables; (4) to determine man's limits when he must use manipulators and remote viewing systems. The AIMM (Acoustic Imaging Displays with Mechanical Manipulator) system will be used as a prototype for this evaluation. Initially, we will define the limits of conventional deep-dive viewing systems from the human engineer's point of view.

4. Approach: Full-scale dynamic simulation techniques will be used for this investigation. Parametric manipulation of variables, such as back-scatter, visibility, and operator control configuration, will be conducted in the laboratory. During year 1, baseline information will be collected on conventional optical viewing systems. This information will be used later for comparative purposes.

5. Progress:

6. Reference:

ADVANCED MANUFACTURING METHODS - 963-7 81C726-9811135
(FEB 78-APR 78)

1. Responsible DOD organization: Air Force Materials Laboratory
Metals Branch
Wright-Patterson Air Force Base
Ohio 45433
Attn: D. L. Shunk
(513) 257-1110 X52203

2. Performing organization: CAM-I Computer Aided Manufacturing Inc.
Arlington, TX
Attn: C. Link

3. Objective: The objective os this effort is to establish planning specifications in four critical areas of the Air Force program for integrated computer-aided manufacturing (ICAM). These specifications will be used in the short- and long-range planning and performance of the Air Force ICAM program.

4. Approach: This effort will assess the state-of-the-art and establish planning specifications in the technical areas of: (1) geometric modeling; (2) advanced N/C; (3) sculptured surfaces; and (4) process planning.

5. Progress: The first year's membership and project sponsorship in CAM-I (Computer-Aided Manufacturing-International) have been valuable to the success of ICAM. CAM-I fostered four (4) projects in 1977. These were sculptured surfaces, geometric modeling, advanced N/C, and process planning. All of these serve as excellent precursor, small projects to full-scale ICAM projects. The sculptured surfaces and geometric modeling projects shall be used in FY78 and FY79 as data points for an ICAM project in geometric definition. Advanced N/C may be valuable for the robotics project of ICAM as well as the sheet metal fabrication machine design. Process planning has just begun to be useful as a lead in to a major ICAM direction in generative process planning. Documents of the project deliverables have arrived at Air Force Materials Laboratory, as well as a series of four (4) computer tapes, which encompass the sculptured surfaces software.

6. Reference:

ROBOTIC SYSTEM FOR AEROSPACE BATCH MANUFACTURING 71C831-8X11914
(JUN 78-DEC 79)

1. Responsible DOD organization: Air Force Materials Laboratory
Wright-Patterson Air Force Base
Ohio 45433
Attn: M. J. Moscynski
(513) 257-1110 X52562

2. Performing organization: Lockheed Aircraft Corporation
Marietta, GA
Attn: D. Taylor

3. Objective: The object of this effort is to demonstrate the shop floor capabilities of existing robots to drill and route Aerospace sheet metal panels and to establish improved software and control systems to enhance robot programming and versatility and to make the robot more adaptable to the production floor. The functional requirements for the use of robots in assembly shall also be defined.

4. Approach: A three-task program will be undertaken. These tasks will be closely inter-related. Task I will address the demonstration on the shop floor of an existing robot drilling and routing of aircraft sheet metal panels. Task II will establish vastly improved robot software and control systems and demonstrate this enhanced capability. Task III will define the functional requirements for the use of robots in assembly of aircraft sheet metal components.

5. Progress: An in-depth study and analysis of current and conceptual robotic assembly technology, applied to Aerospace batch manufacturing, have been made. Analysis of robotic assembly has been pursued through application of critical economic and sociological factors expected to influence the application and acceptance of automated assembly technology. Several robotic assembly cells and other robotic cell concepts have been examined.

6. Reference:

ROBOTIC SYSTEM FOR AEROSPACE BATCH MANUFACTURING 71C832-8B11914
(SEP 78-MAR 80)

1. Responsible DOD organization: Air Force Materials Laboratory
Computer Integrated Manufacturing Branch
Wright-Patterson Air Force Base
Ohio 45433
Attn: M. J. Mocynski
(513) 257-1110 X52562

2. Performing organization: General Dynamics Corporation
Fort Worth, TX
Attn: D. Golden

3. Objective: The object of this effort is to demonstrate the shop floor capabilities of existing robots to drill and route Aerospace sheet metal panels and to establish improved software and control systems to enhance robot programming and versatility and to make the robot more adaptable to the production floor. The functional requirements for the use of robots in assembly shall also be defined.

4. Approach: A three-task program will be undertaken. These tasks will be closely inter-related. Task I will address the demonstration on the shop floor of an existing robot drilling and routing of aircraft sheet metal panels. Task II will establish vastly improved robot software and control systems and demonstrate this enhanced capability. Task III will define the functional requirements for the use of robots in assembly of aircraft sheet metal components.

5. Progress: The robotics application guide is 80 percent complete and the detailed plans for the fabrication cell have been delivered to the Air Force Materials Laboratory.

6. Reference:

AUTOMATION OF THERMAL SPRAY PROCESS 814-6
(FEB 76-MAY 80)

1. Responsible DOD organization: Air Force Materials Laboratory
Wright-Patterson Air Force Base
Ohio 45433
Attn: S. G. Lee
(513) 257-1110 X52203

2. Performing organization: General Electric Company
Cincinnati, OH
Attn: F. Hermanek

3. Objective: To establish automated process of thermal spray, especially for clearance control coatings so that the spray is reproducible and the spray environment meets OSHA coating requirements.

4. Approach: All variables of the thermal spray process will be identified and those that are controllable will be analyzed. Control systems will be developed to maintain the controllable variables within certain limits and feedback control will permit the process to be automated and computer controlled, thus removing the operator from the poor working environment.

5. Progress: The Materials Laboratory initiated a program in June 1976, entitled, "Manufacturing Technology for Automation of the Thermal Spray Process with General Electric Aircraft Engine Group", to improve process control of the thermal spray process through computer-aided automation. Significant improvement in process control was attained through this program. Controllable variables affecting coating quality were identified. The process parameters governing these variables were subsequently optimized using statistically-designed experiments. Plasma gun power settings, powder feed rates, primary and secondary gas flow rates, gun and part manipulation speeds/attitudes, and other critical process parameters were adaptively controlled through an interfaced minicomputer. System capability was demonstrated by spraying TF39 spools and Stage I HPT turbine blades with the computer-controlled 5-Axis gun manipulator system established under the program. Metallurgical examination and evaluation revealed that these coatings met existing quality standards for bond strength, microstructure, and other properties.

6. Reference: Details concerning this project can be found in technical report AFML-TR-79-4186 on Process Automation.

AUTOMATED COMPOSITE MATERIAL TRANSFER - 407-7
(OCT 77-JUN 80)

1. Responsible DOD organization: Air Force Materials Laboratory
Wright-Patterson Air Force Base
Ohio 45433
Attn: P. F. Pirrung
(513) 257-1110 X55429

2. Performing organization: Northrop Corporation
Hawthorne, CA
Attn: R. Johnson

3. Objective: The objective of this program is to establish and demonstrate low cost composite aircraft component ply layup by adaptation of industrial robotics to automated ply transfer techniques.

4. Approach: Establish the capability to pickup, transfer, and accurately locate composite plies by means of an automated, robotic system. Conduct an initial cost analysis and production payoff projections. Re-assess transfer head requirements and demonstrate concept. The robotic composite ply transfer concept shall be evaluated for its applicability to full-scale composite ply transfer in production and shall reduce the concept to practice. The contractor shall fabricate a full-scale composite monolithic aircraft skin, typical of the skin of a fighter empennage structure, utilizing the complete capabilities of the manufacturing concept.

5. Progress: The establishment of a sector-controlled vacuum transfer head, for use with a off-the-shelf, 6-axis industrial robot, to stack composite prepreg plies into a layup tool automatically was accomplished. Principal areas of accomplishment of the final transfer head configuration are: (1) utilization of graphite composites in the head structure to minimize transfer head weight; (2) evaluation of soft-closed cell foam materials for optimization of the pickup head surface; (3) establishment of air/vacuum flow characteristics of the transfer device to maximize transfer efficiencies; and (4) development of electronics and wiring harnesses for operation of the sector control valves.

6. Reference:

NBS ROBOTIC SUPPORT 81C814-8X11915
(MAY 78-JUL 80)

1. Responsible DOD organization: Air Force Materials Laboratory
Computer Integrated Manufacturing Branch
Wright-Patterson Air Force Base
Ohio 45433
Attn: M. J. Moscynski
(513) 257-1110 X52562

2. Performing organization: National Bureau of Standards
Gaithersburg, MD
Attn: G. Vandenbrug

3. Objective: To obtain NBS expertise to continually assess and make recommendations on an Air Force ICAM project, entitled, "Robotic Systems for Aerospace Batch Manufacturing." In addition, NBS participation in the areas of computer languages, hierarchical control systems, and interfaces shall aid in the wide acceptance and use of the technology which results from the Air Force's robotic effort.

4. Approach: This effort will draw upon the existing expertise of NBS as one of the leading research laboratories in robotics in the world and upon the extensive industry contracts maintained by NBS. Three major tasks shall be conducted: (1) develop a guideline for the selection and procurement of robots, robot computer languages, and robot control systems for Aerospace batch manufacturing; (2) provide technical support to the Air Force and to Air Force contractors on the implementation of robot systems as required by the above-referenced effort; and (3) directly support computer control, programming, and sensor technology to substantially improve robot system performance and safety.

5. Progress: The glossary of robotic terms has been substantially completed. Assistance to the project 914A, B, and C contractures has been provided on numerous occasions. A preliminary analysis of a new vision hardware system was prepared and documented. Hardware for a vision system to acquire binary images has been simulated for part positioning. The design of a graphic simulation system which shows how a robot will function under a program written in an offline mode was begun. Robotic safety issues have been pursued.

6. Reference:

ROBOTIC SYSTEMS FOR AEROSPACE BATCH MANUFACTURING 71C812-8811914
(JUL 78-OCT 81)

1. Responsible DOD organization: Air Force Materials Laboratory
Wright-Patterson Air Force Base
Ohio 45433
Attn: G. E. Mayer
(513) 257-1110 X52562

2. Performing organization: McDonnell Douglas Corporation
St. Louis, MO
Attn: G. E. Ennis

3. Objective: The object of this effort is to demonstrate the shop floor capabilities of existing robots to drill and route Aerospace sheet metal panels and to establish improved software and control systems to enhance robot programming and versatility and to make the robot more adaptable to the production floor. The functional requirements for the use of robots in assembly shall also be defined.

4. Approach: A three-task program will be undertaken. These tasks will be closely inter-related. Task I will address the demonstration on the shop floor of an existing robot drilling and routing of aircraft sheet metal panels. Task II will establish vastly improved robot software and control systems and demonstrate this enhanced capability. Task III will define the functional requirements for the use of robots in assembly of aircraft sheet metal components.

5. Progress: The production integration plan, high-level language plan, and off-line programming plan have been been approved by the United States Air Force technical monitor. Major system components and their inter-relationships within these areas have been determined through the use of modular breakdowns. The micro-robotic simulation model is being developed and coded to analyze the manufacturing cell operation. Development of the high-level robot programming language has resulted in design specifications for seven of the modules. Test plans for the language and interface software have been prepared. Tests were conducted on the quick change mechanisms for the end effectors. Design, coding, and test specifications have been documented for the GE TN2200 camera interface. The drivematic automatic riveter has been tested. Two patent disclosures have been made, one for a bristled table surface from which to pick up flat parts, and one for the design of a quick change end effector mechanism.

6. Reference:

RESEARCH ON PARALLELISM IN PROBLEM-SOLVING SYSTEMS
(SEP 79-OCT 81)

1. Responsible DOD organization: Air Force Office of Scientific Research
Director of Mathematical/Information Sciences
Bldg. 410, Bolling Air Force Base
Washington, DC
Attn: W. R. Prince
(202) 767-5025

2. Performing organization: SRI International
Menlo Park, CA
Attn: N. J. Nilsson

3. Objective: Explore the basic issues involved in generating problem-solving plans that exhibit parallelism and develop and evaluate techniques for generating such plans. The results of this research could be applied in the development of systems for automatically generating operational plans in a command and control environment and for coordinating the activities of multiple robots involved in a common task (such as remotely-piloted vehicles).

4. Approach: The basic approach is to generate plans in a hierarchical fashion. At the top level, the overall task is divided into a set of high-level steps. At succeeding levels, the steps are expanded into a set of finer, more detailed steps until the plan is described in terms of 'elementary' steps requiring no further decomposition. At each level, the plan will be examined to identify the steps that can proceed in parallel subject to the constraints of available resources.

5. Progress: The first year of this project was spent examining issues involved in exploiting parallelism in problem-solving systems and experimenting with an existing problem-solving system, NOAH. The purpose of the experiments was to develop techniques for recognizing and exploiting opportunities for parallelism. Several improvements were made to the NOAH systems. The improvements include a new procedure for resolving conflicts, a new critic, and a new routine for printing out procedural networks as a diagram. In developing plans, situations arise when one branch of a procedural network has side effects which interfere with the actions in a parallel branch. A technique using signal and wait nodes to synchronize potentially conflicting actions was incorporated into the planning system.

6. Reference:

MATERIALS-HANDLING EQUIPMENT FOR SUPPLYING THE ARMY IN THE FIELD UNDER THREAT SCENARIOS

1. Responsible DOD organization: MERADCOM Programs Office
Ft. Belvoir, VA 22060
Attn: P. Hopler
(AVN) 8-354-3471

2. Performing organization: MERADCOM Programs Office
Ft. Belvoir, VA 22060
Attn: J. Stephens
(703) 664-3471

3. Objective: Conduct exploratory research of new and emerging technology which can be exploited to enhance the military supply distribution to the Army in the field.

4. Approach: By a concerned effort on in-house and contractual support, conceive and evaluate mechanisms, techniques, materials, and integrate them into systems that will enhance the Army's ability to supply the Army in the field under various threat scenarios including trasition to war, RDF, and full mobilization.

5. Progress: Awarded contracts to determine operational requirements for ammunition resupply in the 1990's and to determine boundary conditions for MHE required to transition to war. Completed investigation and preliminary feasibility analysis of robots as an alternative for transfer of ammunition under an NBC threat.

6. Reference:

ARMY APPLICATION OF ROBOTICS

1. Responsible DOD organization: DARCOM Human Engineering Laboratories
Aberdeen PG, MD 21005
Attn: B. E. Cummings
(301) 278-4401

2. Performing organization: DARCOM Human Engineering Laboratories
Aberdeen PG, MD 21005
Attn: C. M. Shoemaker
(301) 278-3265

3. Objective: To obtain an early appreciation of the potential for current (off-the-shelf) and near-term robotic technology to provide enhanced performance of available manpower and materiel in an environment characterized by limited personnel resources and reduced performance capabilities of troops encumbered by NBC protective equipment. Specifically, initial design and procurement of materials to construct a robotic ammunition transport device will take place in FY81. This system will be designed to reduce the labor intensive activities associated with loading 8-inch projectiles on the M110 E2 S.P. Howitzer.

4. Approach: Traditional study and survey methods will be supplemented by an active demonstration program utilizing the robotic ammunition transport device referred to above. The design and fabrication of this device will be performed in conjunction with Toole Army Depot.

5. Progress: The preliminary design for the system has been completed (HEL, AEO, Shipley Mfg, and Unimation Participation) and orders have been placed for a Unimate 4000 and DEC PDP 1103.

6. Reference: DAOD4946

SPEECH RECOGNITION

1. Responsible DOD organization: DARPA

2. Performing organization: System Development Corporation
Santa Monica, CA 90406
Attn: H. B. Ritea

3. Objective: Development of an automatic speech understanding system which, in its final implementation, will have a vocabulary of 1,000 words and will allow a number of speakers to use natural-spoken English to access information in a data base.

4. Approach: Successful implementation of a speech understanding system requires the use of several sources of knowledge about language and its use for particular tasks. These include the parameters of speech sounds, acoustic-phonetic data, lexical data, phonological data, semantic data, and stored information about an ongoing dialogue. A major concern in th system-building strategy is the interconnection and scheduling of these knowledge sources, commonly referred to as the system architecture. The basic approach taken to system implementation is distinguished by a "best-first" parsing strategy and a probabilistic acoustic-phonetic processor. The key features of this parsing strategy are the assigning of priorities at each step along a parsing path and the suspending of a path when there are alternatives available with higher priorities.

5. Progress: By the end of 1975, a prototype of the 1,000-word vocabulary system targeted for 1976 will be implemented. This system will have a 600-word vocabulary. Acoustic-phonetic and parametric processing will be done on a PDP-11/40 and SPS-41 computer configuration. All higher-level linguistic processing and lexical mapping will be done on an IBM-370/145. Continued research in acoustic-phonetics and parameterization will lead to more accurate A-matrices. Further work in lexical mapping, particularly in methods for hypothesizing words purely on the basis of acoustic cues, will enable the system to partially break away from a purely predictive strategy based on linguistic cues. Analysis of protocols will lead to a more comprehensive syntax for the data management task, in addition to providing useful information for building discourse structures of dialogues.

6. Reference:

ARMY ROBOTICS
(OCT 81)

1. Responsible DOD organization: OCE ETL Research Institute

2. Performing organization: OCE ETL Research Institute

Attn: Dr. R. D. Leighty
(703) 664-3220

3. Objective: Definition of a detailed Army R&D program for robotics to effectively replace or assist combat, combat support, and combat service support personnel.

4. Approach: The baseline for a program in robotics will be a contractual effort having four phases: (1) organize robot technology in a manner that defines the basic functional criteria necessary for designing robots within significant categories of potential Army applications based on prioritized mission area needs or technological opportunities; (2) define the state-of-the-art for 4980 and extrapolate to 1990 and 2000 in each category; (3) detail an Army research plan for each category which considers, for example, risks, cost/benefit, schedules, priorities, etc.; and (4) identify the potential for initiation of developments (e.g., 6.3, 6.4) based on the natural and accelerated state-of-the-art. In-house activities will involve independent study and training, visits to industrial and university robotic facilities, liaison with government organizations, and coordination within Army. The end-item plan will be the product of internal evaluation and analysis of the contracted baseline work as enabled by the in-house activities described above.

5. Progress:

6. Reference:

ROBOTICS APPLIED TO RAPID EXCAVATION
(SEP 81)

1. Responsible DOD organization: MERADCOM Countersurveillance Intrusion Lab
Sensors and Survivability Division

2. Performing organization: MERADCOM Countersurveillance Intrusion Lab
Sensors and Survivability Division
Attn: Mr. H. L. Keller
(803) 664-5876

3. Objective: To investigate an approach to the use of robotics in conjunction with an on-going Army need to develop rapid excavation techniques.

4. Approach: Perform preliminary evaluations of means of converting an existing excavator, a tractor mounted backhoe, to computer-assisted control.

5. Progress: Progress has been made in: (a) development of microprocessor-based controller software and definition of hardware requirements; (b) evaluation of means of sensing digger and hole states; and (c) evaluation of means of digger actuation under microprocessor control.

6. Reference:

CONTROL CONCEPTS FOR ROBOTIC TURRET
(JAN '2)

1. Responsible DOD organization: Arradcom Systems Division (FC & SCWSL)

2. Performing organization: Arradcom Systems Division (FC & SCWSL) Attn: T. Posbergh (201) 328-2221

3. Objective: Develop advanced intelligent control concepts and methodology compatible with requirements of complex military robotic systems.

4. Approach: Analytical and computer-aided design tools will be developed to permit design of high-performance robotic controls and investigations will be carried out to address software/hardware architectural issues associated with implementing complex robotic control algorithms. The concepts of trainable controllers and bayesian learning will be investigated for application to military robotic systems.

5. Progress: None. New start.

6. Reference:

PLATFORM ASSEMBLY: ROBOTIC CONSTRUCTION EQUIPMENT
(MAY 82-CONT)

1. Responsible DOD organization: National Aeronautics and Space Administration
Lyndon B. Johnson Space Center

2. Performing organization: National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Attn: W. S. Beckham
(713) 483-3084

3. Objective: To develop technology for the construction and servicing equipment needed in the assembly of a large space platform using the space shuttle orbiter as a construction base.

4. Approach: Previous studies have identified requirements and defined equipment concepts for construction of space platforms. One critical function in construction operations is the holding and positioning of the platform relative to the orbiter to facilitate access to specific work zones by the remote manipulator systems (RMS) and by the extravehicular astronauts. A ground test article (GTA) representing a holding and positioning aid (HPA) concept is being fabricated. This RTOP activity will define and evaluate performance criteria and functional capability through test of the GTA in simulated zero-G operation in the manipulator development facility and the large area space simulator. The berthing and docking function of the interface between the platform and the construction equipment will be evaluated. Based on test results and analysis, technology needs will be assessed and a development program planned for technology issues that would be critical to the development of flight equipment for the orbiter.

5. Progress:

6. Reference:

ADVANCED ORBITAL SERVICES (TELEOPERATOR MANEUVERING SYSTEM)
(JUN 81)

1. Responsible DOD organization: National Aeronautics and Space Administration
Marshall Space Flight Center

2. Performing organization: National Aeronautics and Space Administration
Marshall Space Flight Center
Attn: J. R. Turner
(205) 453-4165

3. Objective: The objective of the FY82 work will be to investigate, define, and develop the teleoperator maneuvering system (TMS) applications, requirements, and concepts to bring to the space transportation system (STS), a remotely-controlled satellite placement, retrieval, and subsatellite capability in the mid-1980's with an evolution to other satellite services such as satellite maintenance/repair, large structures assembly, and retrieval of unstabilized satellites and space debris.

4. Approach: The TMS phase A study initiated in 1980 and incrementally funded in FY81 will be completed in FY82. Supporting development in FY81 includes procurement of a shuttle remote manipulator system (RMS) end effector that will be evaluated during FY82 for use as a docking mechanism. Evaluation of other docking mechanisms, lighting requirements, video, and display requirements will continue to be investigated during FY82. Bread boarding of long- and short-range radar systems will be completed and evaluated in FY82 to assess applicability to the TMS and to determine new technology requirements. The TMS docking systems test and evaluations will be conducted and spacecraft servicing systems/control systems will be extended to include axial and radial exchange capability. Specialized end effectors for handling beams will be fabricated and tested in FY82 to further refine concepts for TMS remote satellite applications.

5. Progress:

6. Reference:

SPACE APPLICATIONS OF AUTOMATION, ROBOTICS, AND MACHINE INTELLIGENCE SYSTEMS (ARAMIS)

1. Responsible DOD organization: National Aeronautics and Space Administration
Marshall Space Flight
Huntsville, AL
Attn: G. Vontiesenhausen
(205) 453-2789

2. Performing organization: National Aeronautics and Space Administration
Marshall Space Flight
Huntsville, AL
Attn: G. Vontiesenhausen
(205) 453-2789

3. Objective: The study provides a cross-cut between major functional elements of representative future NASA mission models and available and expected options of automation, robotics, and machine intelligence systems which would be applied to these functional elements. Required RDT&E investments, costs of software and hardware, and systems integration cost will be determined, as well as cost benefits obtained over using conventional systems. This is an overall systems approach to the role of advanced automation technology application in NASA's future missions.

4. Approach:

5. Progress:

6. Reference:

INTELLIGENT SYSTEMS RESEARCH

1. Responsible DOD organization: National Aeronautics and Space Administration
Langley Research Center
Langley Station, VA
Attn: C. T. Woolley
(804) 827-3871

2. Performing organization: National Aeronautics and Space Administration
Langley Research Center
Langley Station, VA
Attn: C. T. Woolley
(804) 827-3871

3. Objective: The research objective of this plan is to advance intelligent systems technology to enable the design, development, and utilization of advanced systems for future space robotics applications including space assembly, space manufacturing, and space servicing of satellites.

4. Approach: To achieve these objectives, the program focus will be to conceptualize, investigate, and verify algorithms, sensors, actuators, software, and system architecture required for automated space operations. Specific near-term objectives are: (1) development of a prototype multi-arm manipulator to be used for space assembly studies; (2) development of high-speed processing techniques and hardware for specialized algorithms such as numerical integration, filtering, and matrix manipulation; and (3) development of multiple-arm coordination techniques and software.

5. Progress:

6. Reference:

SENSOR/CONTROL AUGMENTATION OF SHUTTLE REMOTE MANIPULATOR SYSTEM
(JUN 81-CONT)

1. Responsible DOD organization: Jet Propulsion Laboratory
California Institute of Technology

2. Performing organization: Jet Propulsion Laboratory
California Institute of Technology

Attn: A. K. Bejczy
(213) 354-4568

3. Objective: Development, demonstration, and evaluation of advanced teleoperator techniques and subsystems for shuttle remote manipulator system (RMS) control, to provide enhanced capabilities for satellite retrieval, maintenance and repair, for in-orbit servicing of reusable vehicles, and for space platform/station assembly such as the space operations center.

4. Approach: The objectives include the development of proximity, force torque, and contact sensor with related controls, integrated graphic displays of sensory information, bilateral force reflecting manual controls, and computer based voice command capabilities for controlling both TV cameras/monitors and graphic displays. The final objective is to demonstrate enhanced and smart sensor/control capabilities in the form of protoflight systems/experiments in the CY84 to 86 time period. The specific FY82 objectives are: (1) conduct and evaluate force torque control experiments at the JSC manipulator development facility (MDF) using the force torque sensor and display system developed at JPL in FY80-81; (2) produce both requirements definitions and preliminary designs for protoflight sensor, control, display, and voice command systems, including protoflight experiements definitions; and (3) initiate component developments where appropriate.

5. Progress:

6. Reference:

MACHINE VISION AND TELEOPERATOR ROBOTS
(JUL 81)

1. Responsible DOD organization: Jet Propulsion Laboratory
California Institute of Technology

2. Performing organization: Jet Propulsion Laboratory
California Institute of Technology

Attn: C. F. Ruoff
(213) 354-6101

3. Objective: Develop and demonstrate sensing, perception, and control technology needed for automated space systems, teleoperators, and robots. Specific objectives include: (1) the development and laboratory demonstration by 1986 of a control-oriented computer vision system which is capable of target body tracking over a noisy background; and (2) the development and demonstration of a supervisory control system with telepresence for remotely-operated teleoperator robots in 1986.

4. Approach: Supporting objectives in 1982 include: (1) developing and testing extensible visual models for three dimensional objects; (2) extending stereo recognition algorithms; (3) increasing the speed of tracking algorithms; (4) performing initial tracking experiments in noisy scenes; and (5) determining realistic design goals and generating a development plan for a supervisory control system with telepresence. The approach to computer vision will focus in the near term on algorithmic as opposed to hardware development. Robust appro ches which can tolerate variability will be sought with attention being paid to their eventual implementation in parallel hardware processing networks. Supervisory control efforts will focus this year upon an analysis of realistic future teleoperator robot requirements as contrasted with available technology. From this work, a technology development plan can be formulated which will be used to guide subsequent research and development activities.

5. Progress:

6. Reference:

ROBOTICS/MACHINE INTELLIGENCE AUTOMATED SYSTEMS

1. Responsible DOD organization: Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA
Attn: C. Ruoff
(213) 354-6101

2. Performing organization: Jet Propulsion Laboratory
California Institute of Technology
Padadena, CA
Attn: C. Ruoff
(213) 354-6101

3. Objective: To develop and demonstrate laboratory versions of sensing and control technologies for automated systems and robots. A specific objective is the development of a visual subsystem for control applications.

4. Approach: In FY81, work toward this objective will include: (1) developing object models useful for tracking of three-dimensional objects; (2) developing stereo object recognition algorithms for simple objects in arbitrary poses; (3) developing initial stereo tracking algorithms which work at one-half normal frame rates; and (4) cooperating with NASA-Goddard on the use of the massively parallel processor prototype in real-time scene analysis.

5. Progress:

6. Reference:

APPENDIX G:

THE AUTOMATED MANUFACTURING RESEARCH FACILITY OF THE NATIONAL BUREAU OF STANDARDS

The Automated Manufacturing Research Facility of the National Bureau of Standards

J. A. Simpson, R. J. Hocken, J. S. Albus, Center for Manufacturing Engineering
National Engineering Laboratory
Washington, D.C.

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Abstract

A major facility for manufacturing research is being established at the National Bureau of Standards (NBS). The facility is designed to provide extreme flexibility and to be capable of emulating a wide variety of manufacturing cells typical of a small machine job shop. The control architecture adopted is hierarchical in nature and highly modular. The facility will be used for research on interface standards and metrology in an automated environment.

Keywords: Automated Machining, Hierarchical Control, Manufacturing Research, Research Facility.

The Congressional Act* setting up the National Bureau of Standards charges the Bureau with:

1. The custody, maintenance, and development of the national standards of measurement, and the provision of means and methods for making measurements consistent with those standards.
2. Cooperation with other government agencies and with private organizations in the establishment of standard practices, incorporated in codes and specifications.

To perform these functions, the Bureau has, over the years, installed numerous experimental facilities, including a nuclear research reactor, a linear accelerator, and dead weight force generators with a capacity of 4.4 meganewtons. The National Bureau of Standards has recently embarked on the design, procurement, and installation of a new Automated Manufacturing Research Facility (AMRF) to support its measurement and standards responsibilities in the decades of the 1980s and 1990s. When completed in 1986, this facility will be capable of full-scale emulation of the flexible machining cells in the automated factory of the future.

Purpose of the AMRF

The Automated Manufacturing Research Facility will reside in the Center for Manufacturing Engineering which was founded to supply to the mechanical manufacturing sector the services described in the enabling legislation and to carry on a research program to develop "means and methods" for making the measurements that will be needed by this sector in the future. The Center currently provides a wide range of calibration services for mechanical artifact standards such as gage blocks, thread gages, and line scales as shown in *Figure 1*.

These artifact standards, many of which were developed by NBS in the first three decades of this century, are idealized models of the products to

*Act of 22 July 1950, 64 Stat. 371 (Public Law 619, 81 Congress)—An Act To amend section 2 of the Act of March 3, 1901 (31 Stat. 1449), to provide basic authority for the performance of certain functions and activities of the Department of Commerce, and for other purposes.

Figure 1
Artifact Standards Typical of those now Calibrated by NBS

which they are compared. The comparisons (calibrations) are organized according to statistical quality control methods developed during and immediately after World War II. Artifacts currently are the basis for the National Measurement System which provides nation-wide dimensional compatibility by a chain of comparisons back to National Standards. The system has remained virtually unchanged since the 1940s, except for the introduction in the 1960s and '70s of the concepts of Measurement Assurance Programs (MAP)[1], which emphasize the system aspects of measurement and introduced the concepts of closed loop feedback into metrology management.

Manufacturing technology, however, has not remained unchanged. The introduction of numerically controlled machines, group technology concepts, and the first steps toward Flexible Manufacturing Systems (FMS) in the 1960s called attention to the labor intensive nature, high skill requirement, and time consumption of classic metrology.

The first effort of NBS to meet the up-coming challenge was in 1968 when a research program was mounted to investigate the possiblility of automating surface plate metrology by the use of the then new computer controlled coordinate measuring machines (CMM). A decade of work realized a measurement system based on such machines where the "product-like" artifact standards of the past were replaced with measurement protocols based on laser interferometer techniques for characterizing the measuring system (coordinate measuring machine) itself. Transfer standards were developed that permitted such machine or process characterization to be economically realized on machines of lesser but known precision[2]. The three-dimensional ball plate on the table of the CMM in *Figure 2* is one of the latest of such standards. These new measurement

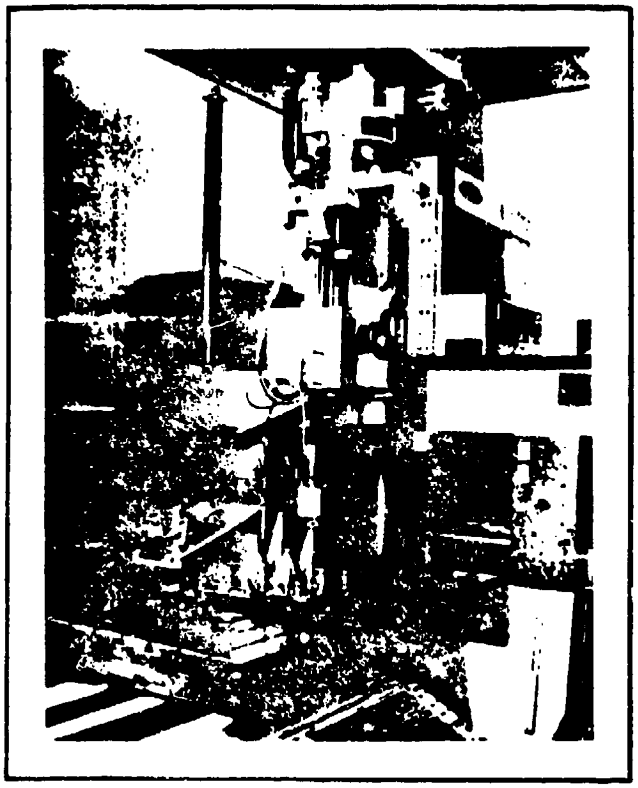

Figure 2
Coordinate Measuring Machine, with He-Ne Laser Scales under Computer Control, Calibrating a 3-Dimensional Ball Plate used to Characterize Similar Machines at other Locations

methods are rapidly becoming the norm for certain part families. These families are medium to large in size and complex-prismatic in nature, and hence similar to the output of the first and second generation FMS.

Even before this work was completed, it became obvious that there were many part families that were ill-suited to measurement by CMM. Small parts, turned parts, and very simple parts are all either very difficult or uneconomic to measure in this manner. Moreover, the rapid development of FMS, with the ability to reduce inventory by shorter runs, casts doubt on the continuing usefulness of any QC system which depends on statistical sampling. Along with others, NBS became convinced that the QC system of the future would increasingly depend on characterization of the process, monitoring of the machine parameters, and adaptive control rather than measurement of part parameters after the process, or a step in the process, was complete. Such a development will require NBS to provide the "means and methods" of measurement where the measurements are deeply embedded in the process.

The total Bureau experience has amply demonstrated that one cannot learn to measure without "hands on" experience, and every attempt to attack measurement problems on a purely theoretical basis has proved less than satisfactory. Therefore, in cooperation with the Bureau of Engraving and Printing, an NC machining center was set up in the NBS Instrument Shop to explore the measurement problems involved in assuring part dimensional accuracies by machine calibration. It was soon shown that the calibration techniques and software correction algorithms for static errors developed on coordinate measuring machines could be applied to machine tools in a shop environment. A five-fold increase in accuracy was demonstrated. *Figure 3* illustrates the degree of correction obtained for a milling center.

The correction of dynamic errors such as thermal distortion due to internally generated heat or distortion due to cutting forces needs further research, but appears to present no insurmountable obstacles. Certain complex dimensional measurements such as drill condition and tool setting are needed, but modern microcomputer based technology appears adequate to the task.

The AMRF will allow research in measurement technology to be expanded to include those system elements at the cell (multiwork station) level. The AMRF will provide a test bed where integrated manufacturing system measurement research can be performed.

The AMRF will provide a test bed for research directed toward the "establishing of standard practices". If flexible manufacturing systems are to become widely adopted in the discrete parts industry where 87% of the firms employ less than 50 persons, they must become much more modular then they are today. It must become possible for a firm to start with an NC machine, add a robot, add another machine, and so on as capital is accumulated and as the firm's business grows. Systems must also be capable of being tailored to various part mixes without extensive engineering effort. However, before this degree of flexibility can be accomplished, interface standards must be adopted so equipment of diverse origin can be integrated incrementally into the systems.

The first steps in this direction have already been taken. Under Air Force Integrated Computer Aided Manufacturing (ICAM) sponsorship, the NBS coordinated the efforts of a consortium of 45

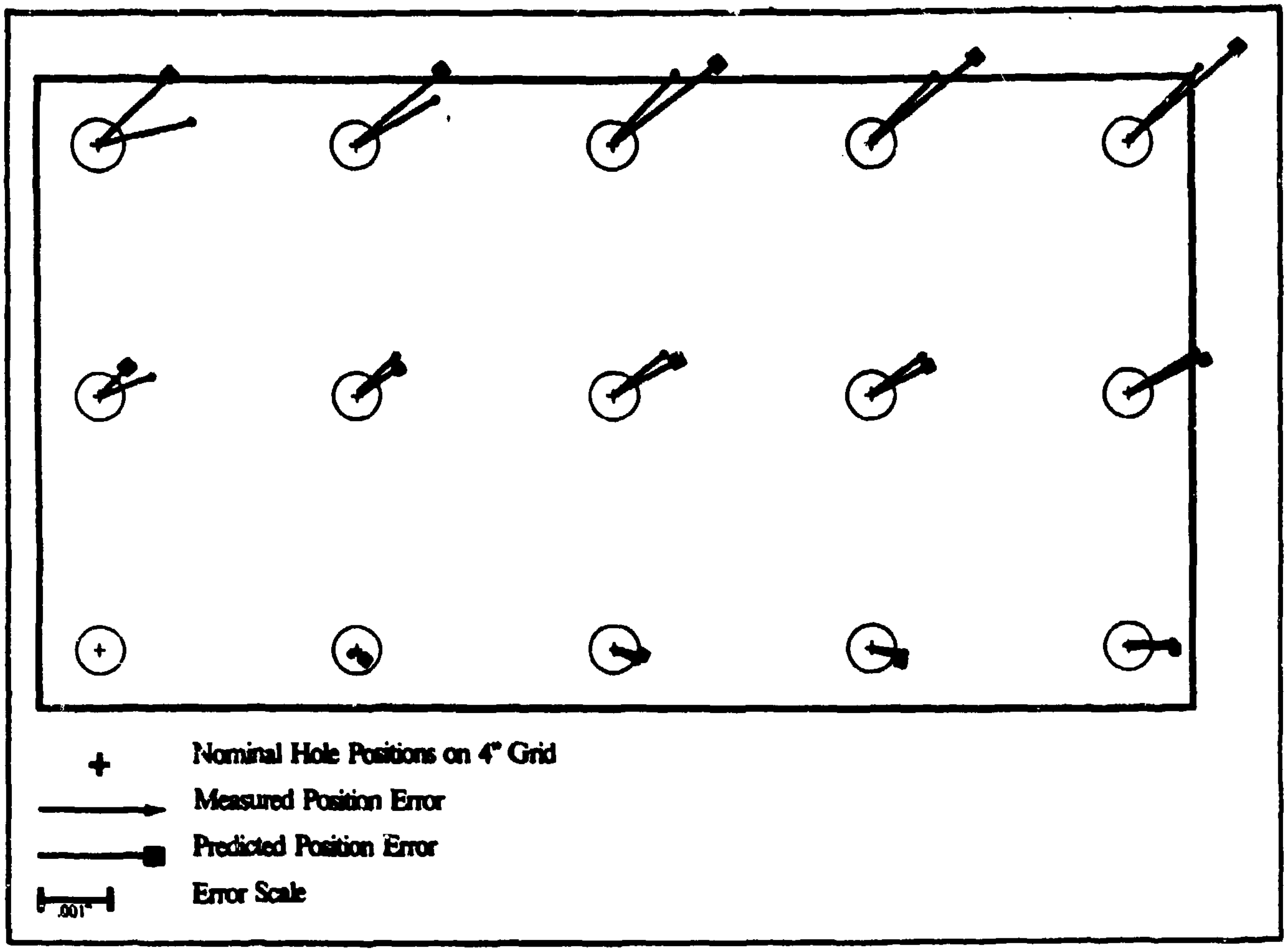

Figure 3
The Error Map of the X-Y Plane of a Machining Center. Shown are the actual performance, measured from a hole plate compared with predicted performance obtained by measurements using laser interferometry.

private firms to generate the Initial Graphic Exchange Specification[3] (IGES). IGES is a common public domain data format which allows geometric data to be exchanged between two different types of computer aided design systems, or between a computer aided design and a computer aided manufacturing system. IGES thus allows access to the geometric data bank of a computer aided design system without the necessity of producing a drawing. IGES has recently been incorporated into a national standard (ANSI Y14.26M). The development of this standard is important for its intrinsic value; but perhaps more important, it has demonstrated that such interface standards can be structured and generated in a manner which provides full protection for proprietary interests. The AMRF will provide a test bed for the development of similar interface standards for integrated manufacturing systems. It will allow the test and verification of interface standards in an open and nonproprietary atmosphere.

Description of the AMRF

The Automated Manufacturing Research Facility will superficially resemble a FMS designed to handle the bulk of the part mix now manufactured in the NBS Instrument Shop. This part mix has been studied using Group Technology[4] concepts and is shown to be similar to a typical job shop. The parts

manufactu ed will fall within the following limitations:

1. Weight: Less than 50 kilograms (100 lbs).
2. Size, Prismatic: 300 mm cubes (12" x 12" x 12").
3. Size, Rotational: 250 mm diameter x 250 mm length (10" x 10").
4. Parts Run: 1 to 1,000 pieces.
5. Complexity: Up to 4 axes prismatic.
6. Materials: Steel, stainless steel, aluminum, brass, iron, lucite.

The AMRF and the research performed on it will address only the manufacture of individual parts by chop forming metal removal. Hence, the unit operations will include only: fixturing, milling, drilling, reaming, tapping, boring, turning, facing, threading, cleaning, deburring, and inspection. Such problems as automated assembly, welding, hardening, and finishing will not be addressed.

The AMRF hardware is structured around the concept of single self-contained work stations, each with a well defined set of functions which can be useful as a stand-alone entity. The current plan calls for the existence of eight such stations with varying degrees of complexity of function. They are:

1. Horizontal Machining Station.
2. Vertical Machining Station.
3. Turning Station.
4. Cleaning and Deburring Station.
5. Inspection Station.
6. Materials Inventory Station.
7. Transfer System (station).
8. Housekeeping System (station).

Items 7 and 8, the Transfer and the Housekeeping Systems are not strictly stations since they are nonlocalized in the facility. From the point of view of the control system, however, they will be treated as stations.

The Materials Inventory Station will be used as a buffer to allow storage of sufficient material for several days of operation and an automatic inventory for much of the raw material requirements of a job shop. If such a system were to serve simply as a buffer, ony three or four days storage would be required, that is, enough for automatic operation through a long weekend. Since it is not the purpose of this program to study such systems *per se*, one week of storage was chosen as a reasonable trade off between the requirements of the simple buffer (or interface to the manual world) and a much more elaborate total system inventory. At this stage we plan to use the inventory system for the storage of raw material blanks, tools and tool holders (assembled), special fixtures, and finished parts or parts in-process. The inventory system will be loaded and unloaded manually while the facility is in operation.

The Materials Transport System will provide the means of moving parts, tooling, and fixtures within the facility. Two mechanisms will be used. One, a carousel, will also serve as the inventory system. The second, a robot cart or automated guided vehicle (AGV), will allow great flexibility in layout and easy access to the machines[5]. Although, the transfer system itself is not seen as a primary research area for NBS, the interfaces between the work stations and the transfer system will be designed to accommodate many different types of systems as well as other options in order to maintain modularity.

The machine tools were chosen to be representative of the types of general purpose machine tools in common use throughout the U. S. The choice also matches the specific needs of the NBS Instrument Shops as revealed by the Group Technology Study. Each of the machines will be configured into a work station with a single industrial robot.

NBS has chosen to use standard, modern, general purpose machine tools in the construction of the AMRF. This is a different strategy than that taken by two other well known national programs in automated batch manufacturing, the British A.S.P. plan[6], and the Japanese MUM or FMC plan[7]. Both of these other programs have assumed *a priori* that current machine tool designs are inadequate for an automated research facility. However, based on an international study of the state-of-the-art in machine tool science[8], NBS has decided that this assumption is highly questionable. We have chosen to rely on the engineering experience of a well-developed industry rather than a radical new design. Should problems arise in reliability, reparability, and chip removal, we plan to subcontract any needed modifications to the same industry.

Cleaning and deburring was made into a separate function (and station) because of the importance of this task for automatic inspection. As many deburring operations as possible will be carried out at the machining site. Nevertheless, there appears to be no way to avoid cleaning and

deburring as a separate operation in all cases. Studies have revealed that the cost for cleaning and deburring in batch manufacturing is high and often unrecognized[9].

The Inspection Station will be a modified four axes horizontal arm measuring machine tended by a robot. It will be very similar to the machining work stations from the control point-of-view. This configuration was chosen primarily for flexibility in use.

The Housekeeping System will provide for the removal of chips during automated operation. Cleanliness during manufacturing and fixturing, and the effects of cutting fluid and chips (dust) on sensors have been serious problems in many of the existing FMS systems[10]. In the AMRF, chip removal is expected to be complicated by the variety of materials, the large number of sensors contemplated, and the decision to address the flexible fixturing problem robotically at the machines. A plan regarding chip removal is being developed at this time through both external[11,12] and internal studies. This system will be kept as simple as possible with little attempt to optimize for long unattended runs.

Layout for the facility is shown in *Figure 4*. This configuration allows easy access to the machines, and the transfer mechanism can be either the automatically guided vehicle system or the central carousel system. Coolant and cutting fluid are recycled at the machine. Buffering is provided to the machines through the row of "file-cabinets" which make up the carousel shown in the center of the model.

The three robots in the lower right are part of the cleaning and deburring station. The separate room at the upper right is the inspection station. The four machining stations each consist of an industrial robot, a machine tool, a localized inventory of tools, fixtures, grippers (end effectors), probes, and interfaces to the transfer and housekeeping systems.

The proposed operational scenario places severe requirements upon the work station and its subelements. Some of these are necessitated by the decision not to palletize and others by the wide part

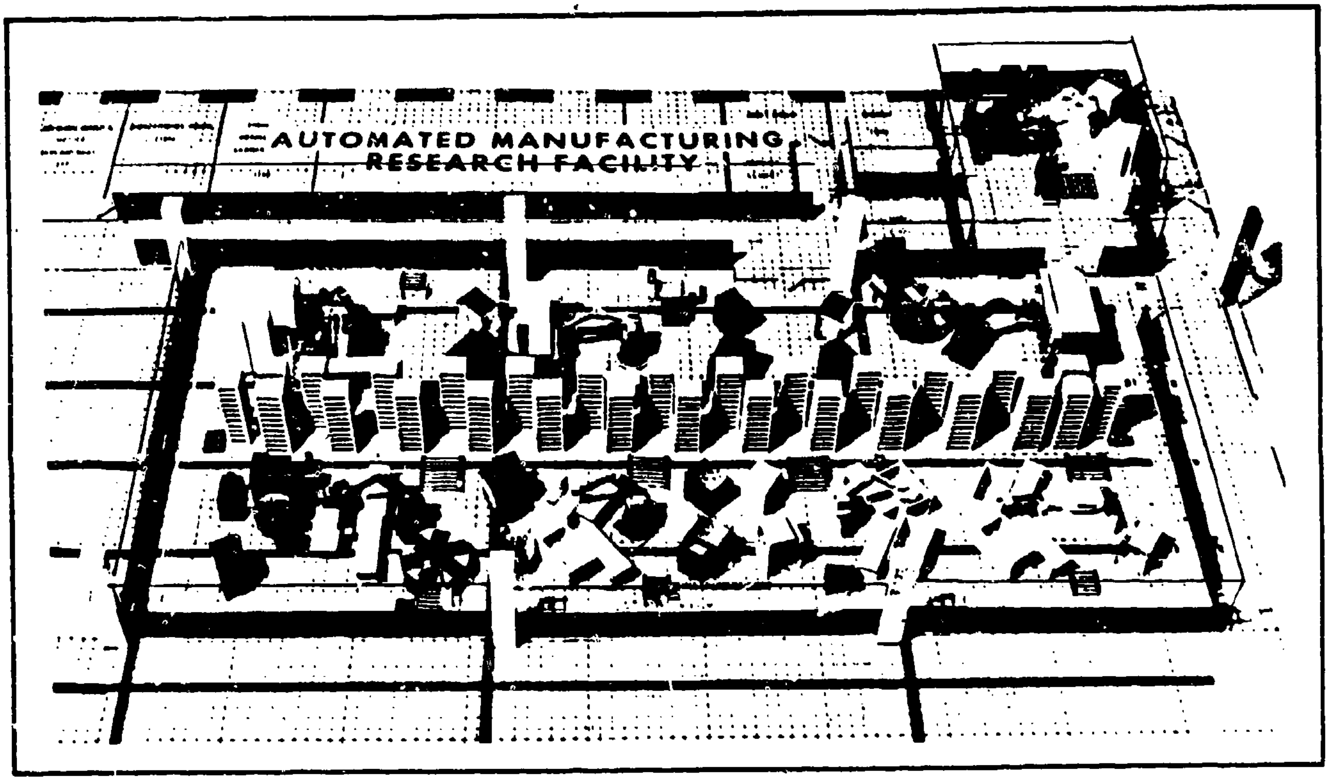

Figure 4
Model of AMRF Showing Location in Instrument Shop. The centrally located carousel will be used to convey material, tools and finished parts. For purposes of environmental control the measuring station is, as shown, in a separate room.

mix envisioned. The tools and material arriving at a work station will not be precisely located in space. This will require advances in the state-of-the-art over current industrial robot capabilities. The robot capabilities will also be stretched by the requirement of fixturing on the machine. The problems of chip buildup and tool wear will be aggravated by the material and part mix contemplated. It is our belief that those requirements will be the norm in second generation FMS systems which will be available in the 1990s.

Table 1 gives a partial list of the functions required of the robots and machine tools in the AMRF. As can been seen, it is intended that the industrial robot be able to locate parts, tools and fixtures, transfer these items to the machine tool, fixture the part, and monitor the process while machining is carried out. Thus the robot will have extended sensory capabilities, the ability to precisely grip and position variable shapes, and considerable manipulative ability to fixture the parts upon the machine tool. In general, solutions to these problems are more difficult for prismatic than for cylindrical workpieces.

To the best of our knowledge, no one has addressed the flexible fixturing problem in any depth though some very elaborate and expensive solutions have been proposed by Tuffensammer[13]. Tool setting on machining centers is in a similarly undeveloped stage, as is generic tool wear/breakage sensing[14]. Our project plan has been to delineate as carefully as possible those areas requiring development, research carefully the state-of-the-art in these areas, and if required, initiate research directed towards the appropriate goal(s).

At present the Center for Manufacturing Engineering has two projects, one in robotics, the other in precision machining. These projects are directed towards the development of the major subsystems required for the AMRF. The integration of these two programs will take place first in the Horizontal Machining Work Station which will be the first work station to be assembled. The architecture and control system hardware for this work station will serve as a model for the other four generically similar work stations.

Although it is recognized that there are important problems of CAD/CAM integration to be solved, the current plans do not include work in this area. Production and process planning systems needed to load the facility will be the largely manual processes currently used for the NC station of the instrument shop.

Table 1
Functions of the Work Station Subelements

Robots Arm Functions

1. Part loading and unloading.
2. Tool loading and unloading.
3. Rough (± 50 mil) part fixturing or fixture assembly.
4. Chip removal and control.
5. Coarse visual inspection of fixtures and parts.
6. Initial part and tool location.
7. End effector selection.
8. Deburring and cleaning (only as needed for next operation).
9. Safety.
10. Self-monitoring.

Machine Tool Functions

1. Machining.
2. Part locations.
3. Tool wear/breakage sensing.
4. Tool setting/checking.
5. Process monitoring (cutting).
   a. Dynamics.
   b. Thermal.
   c. Hydraulics (etc.)
6. Self-monitoring.
7. Deburring and cleaning (as part of the machining operation).
8. Adaptive control.

Control Architecture of the AMRF

In order for the AMRF to serve as a research facility over the next decade, it must exhibit a higher order of flexibility than any currently available FMS. It must not only be capable of very wide part mix, but must also be capable of easy reconfiguration to emulate work stations or small cells operating in the environment of a much larger and perhaps unmanned system. To accomplish these goals requires a control system architecture of considerable sophistication. The conventional Direct Numerical Control (DNC) top down architecture was judged to be unsuitable, primarily because of the inability of such a system to react to feedback from sensors in real-time. In order for an entire machine shop to completely operate automatically, all the machines must be equipped with sensors to

monitor their performance and compensate for irregularities and uncertainties in the work environment. The sensor data must be processed and analyzed, and the results introduced into the machine control systems in real-time so that the response of each machine is goal-directed, reliable, and efficient.

A high degree of sensory-interactive behavior on the part of individual machines creates enormous system control problems for an entire shop. The problem of automatically controlling a number of feedback driven machine tools is much bigger than simply the sum of the control problems for the individual machines. The interactions among many sensory-interactive machines creates a system control problem in which complexity grows exponentially with the number of individual machines and sensor systems. Once there are more than a few machines, each reacting to sensor data in real-time, the overall system control problem can become completely unmanageable. This is the point at which most of the early attempts at building the automatic machine shop failed. The control software for such a system can become enormously complex to write and virtually impossible to debug. The classical solution to control problems of this complexity is to partition the problem into modules and introduce some type of hierarchical command and control structure. The advantage of hierarchical control is that it allows the control problem to be partitioned so as to limit the complexity of any module in the hierarchy to manageable limits, regardless of the complexity of the entire structure.

The use of hierarchical control for industrial applications is not new. It has been employed in controlling complex industrial plants such as steel mills, oil refineries, and glass works for years. However, such hierarchies are usually limited to two or three levels and; most often represent fairly straightforward servo control applications. The uniq features of the control system being planned for the AMRF are the number of hierarchical levels (perhaps as many as seven or eight), and the amount of real-time computation and sensory-interaction at each level. Each hierarchical level will perform a significant amount of real-time computation and will interact dynamically with the shop environment in many different ways. The plan is to build a real-time sensory-interactive control system which at the lower levels will respond to events of millisecond duration (tight servo loops), and at the upper levels will react to events of days or weeks duration (production planning and scheduling problems). The levels in between these extremes will produce intelligent automatic responses to many different types of shop floor conditions and situations.

Figure 5 illustrates the basic logical and temporal relationships in a hierarchical computing structure. This particular example illustrates the control structure for an industrial robot. However, the concepts are readily generalized and will be applied to the entire AMRF.

On the left of *Figure 5* is an organizational hierarchy wherein computing modules are arranged in layers. The basic structure of the organizational hierarchy is a tree. The flow of command and control is vertical. Each node in the tree represents a computing module which receives input commands from only one supervisor module (predecessor node) and issues subcommands to one or more subordinate modules (successor nodes). There may be information flow regarding sensory inputs and internal contextual and sequencing data that flow horizontally and/or rise from lower levels in a cross-coupled network of communication channels, but the primary command and control pathways form a strict hierarchical tree.

At the top of the hierarchy is a single high-level computer module. Here at the highest level, most global goals are decided upon and long-range strategy is formulated. Feedback to this level is integrated over an extensive time period and is evaluated against long-range objectives. Here long-range plans are formulated to achieve the highest priority objectives. Decisions made at this highest level commit the entire hierarchical structure to a unified and coordinated course of action which would result in the selected goal or goals being achieved. At each of the lower levels, computing modules decompose their input commands in the context of feedback information generated from other modules at the same or lower levels, or from the external environment. Sequences of subcommands are then issued to sets of subordinates at the next lower level. This decomposition process is repeated at each successively lower hierarchical level, until at the bottom of the hierarchy there is generated a set of coordinated sequence of primitive actions which drive individual actuators such as motors of hydraulic pistons in generating motions and forces in mechanical members.

Each chain-of-command in the organizational

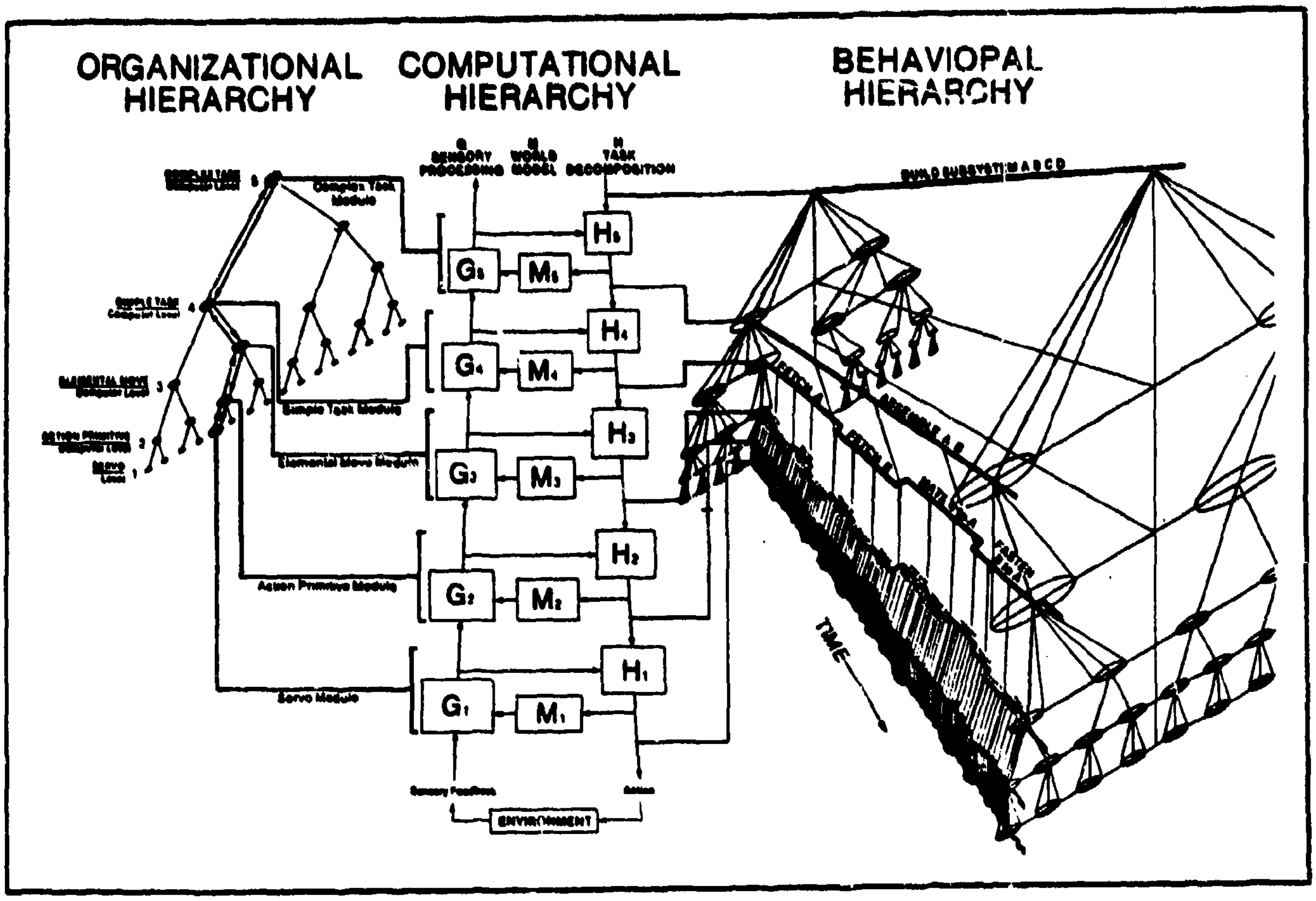

Figure 5
Control System Hierarchy for a "Smart" Robot

hierarchy consists of a computational hierarchy of the form shown in the center of *Figure 5*. This computational hierarchy contains three parallel hierarchies: (1) a task decomposition hierarchy which decomposes high-level tasks into low level actions, (2) a sensory processing hierarchy which processes sensory data and extracts the information needed by the task decomposition modules at each level and (3) a world model hierarchy which generates expectations of what sensor data should be expected at each level based on what subtask is currently being executed at that level.

Each level of the task decomposition hierarchy consists of a processing unit which contains a set of procedures, functions, or rules for decomposing higher level input commands into a string of lower level output commands in the context of feedback information from the sensory processing hierarchy. At every time increment each H module in the task decomposition hierarchy samples its inputs (command inputs from the next higher level and feedback from the sensory processing module at the same level) and computes an appropriate output. A detailed description of such a system as applied to robots has been published elsewhere[15,16,17].

The sophisticated real-time use of sensor data for coping with uncertainty and recovering from errors requires that sensory information be able to interact with the control system at many different levels with many different constraints on speed and timing. Thus in general, sensory information at the higher levels is more abstract and requires the integration of data over longer time intervals. However, behavioral decisions at the higher levels need to be made less frequently, and therefore the greater amount of sensory processing required can be tolerated.

Attempting to deal with this full range of sensory feedback in all of its possible combinations at a single level leads to extremely complex and inefficient programs. The processing of sensor data, particularly vision data, is inherently a hierarchical

process. Only if the control system is also partitioned into a hierarchy can the various levels of feedback information be introduced into the appropriate control levels in a simple and straightforward manner.

The world model hierarchy contains prior knowledge about the task, the parts, and the work environment. Typically, the type of feedback information required by the task decomposition modules at each level depends upon what task is being performed. As conditions change, different sensors, different resolutions, and different processing algorithms may be needed. Given the state of the task execution at each level, the world model can predict what kind of sensory processing algorithms should be applied to the incoming data. Furthermore, sensor data can often be predicted from the actions being executed by the control system.

The world model generates expectations as to what the sensor data should look like. These predictions may be based on previous experience when a similar task was performed on a similar part, or may be generated from a Computer Aided Design (CAD) data base which contains a geometrical representation of the part. The world model hierarchy may contain information as to the shape, dimensions, and surface features of parts and tools and may even indicate their expected position and orientation in the work environment. This information assists the sensory processing modules in selecting processing algorithms appropriate to the expected incoming sensor data, and in correlating observations against expectations. The sensory processing system can thereby detect the absence of expected events and measure deviations between what is observed and what is expected.

Feedback can be used by the task decomposition hierarchy either to modify action so as to bring sensory observations into correspondence with world model expectations, or to change the input to the world model so as to pull the expectations into correspondence with observations. In either case, once a match is achieved between the two, the task decomposition hierarchy can act on information contained in the model which cannot be obtained from direct observation. For example, a robot control system may use model data to reach behind an object and grasp another object which is hidden from view.

If the symbolic commands generated at each level of the task decomposition hierarchy are represented as points in the multidimensional "state-space" consisting of the coordinates of all the degrees of freedom of the machine or robot, and these points are plotted against time, the behavioral hierarchy shown on the right of *Figure 5* results. The lowest level trajectories of the behavioral hierarchy correspond to observable output behavior. All the other trajectories constitute the structure of conditions deep within the control programs.

At each level in the behavioral hierarchy, the string of commands makes up a program. This architecture implies that there is a programming language unique to each level of a hierarchial control system, and that the procedures executed by the computing modules at each level are written in a language unique to that level. This partitioning of the control problem into hierarchial levels limits the complexity of the programming language and the programs at each level. It also generates a whole hierarchy of languages for programming the robots, machine tools, and inspection systems, and for performing, planning and scheduling operations. It is to be noted that such a hierarchy lends itself to the utilization of IGES-type interface standards at each level.

If the control problem is further partitioned along the time axis, an additonal degree of simplicity can be achieved. If time is partitioned into a finite number of computational periods, each computational module can be represented as a finite-state machine. At every time interval, each computational module samples its inputs (command and feedback) and computes an output. The programs resident in each of the computational modules then become simple functions which can be represented by formulae of the form $P=H(S)$, or by a set or production rules of the form IF<S>/THEN<P>. The control structure becomes a simple search of a state transition table.

Each entry in the state-table represents an IF/THEN rule, sometimes called a production. This construction makes it possible to define behavior of high complexity. An ideal task performance can be defined in terms of the sequence of states and state transition conditions that take place during the ideal performance. Deviations from the ideal can be incorporated by simply adding the deviant conditions to the left-hand side of the state-table and the appropriate action to be taken to the

right-hand side. Any conditions not explicitly covered by the table results in an "I don't know what to do" failure routine being executed. Whenever that occurs, the system simply stops and asks for instructions. If the condition can be corrected, a human programmer can enter a few more rules into the state-table and the system can continue. By this means, the system gradually learns how to handle a larger and larger range of problems. This extensibility of the system to new problems is essential in a research facility which, by its very nature, will usually oprate at the very limits of the current state of knowledge.

Such a finite-state machine hierarchical control system has been implemented on a microcomputer network. This network, shown in *Figure 6* has been under evaluation as a control system for the robots in the AMRF[15].

The logical structure of *Figure 5* is mapped into the physical structure of *Figure 6*. The coordinate transformations of *Figure 5* are implemented in one of the microcomputers of *Figure 6*. The elemental move trajectory planning is implemented in a second microcomputer of *Figure 6*. The processing of visual data is accomplished in a third microcomputer, and the processing for force and touch data in a fourth microcomputer. A fifth microcomputer provides communication with a minicomputer wherein reside additional modules of the control hierarchy. It is anticipated that these will eventually be embedded in a sixth microcomputer.

Communication from one module to another is accomplished through a common memory "mail drop" system. No two microcomputers communicate directly with each other. This means that common memory contains a location assigned to

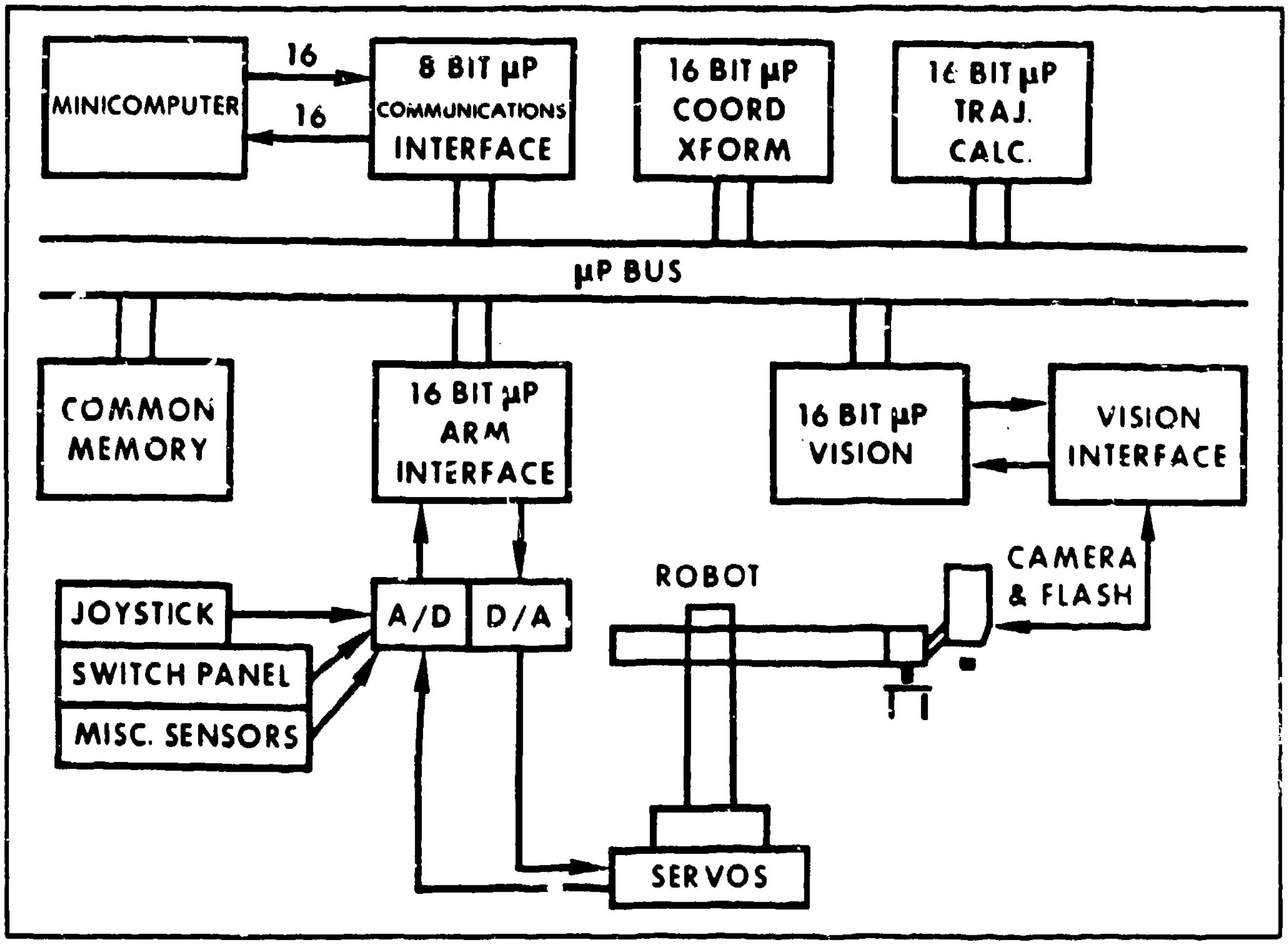

Figure 6
Realization of Hierarchy Utilizing Microcomputer Network with Common Memory for Communication

every element in the input and output vectors of every module in the hierarchy. No location in common memory is written into by more than one computing module, but any number of modules may read from any location.

Time is sliced into 28 millisecond increments. At the beginning of each increment, each logical module reads its set of input values from the appropriate locations in common memory. It then computes its set of output values which it writes back into the common memory before the 28 millisecond interval ends. Any of the logical modules which do not complete their computations before the end of the 28 millisecond interval write extrapolated estimates of their output accompanied by a flag indicating that the data is extrapolated. The process then repeats.

Each logical module is thus a state-machine whose outputs depend only on its present inputs and its present internal state. None of the logical modules admit any interrupts. Each starts its read cycle on a clock signal, computes and writes its output, and waits for the next clock signal. Thus, each logical module is a finite-state machine with the IF/THEN, or P=H(S) properties of an arithmetic function.

The common memory "mail drop" communication system has a number of advantages and disadvantages. One disadvantage is that it takes two data transfers to get information from one module to another. However, this is offset by the simplicity of the communication protocol. No modules talk to each other so there is no handshaking required. In each 28 millisecond time slice, all modules read from common memory before any are allowed to write their outputs back in.

The use of common memory data transfer means that the addition of each new state variable requires only a definition of where the newcomer is to be located in common memory. This information is needed only by the module which generates it so that it knows where to write it, and by the modules which read it so that they know where to look. None of the other modules need know, or care, when such a change is implemented. Thus, new microcomputers can easily be added, logical modules can be shifted from one microcomputer to another, new functions can be added, and even new sensor systems can be introduced with little or no effect on the rest of the system. As long as the bus has surplus capacity, the physical structure of the system can be reconfigured with no changes required in the software resident in the logical modules not directly involved in the change.

Furthermore, the common memory always contains a readily accessible map of the current state of the system. This makes it easy for a system monitor to trace the history of any or all of the state variables, to set break points, and to reason backwards to the source of program errors or faulty logic.

The read-compute-write-wait cycle wherein each module is a state-machine makes it possible to stop the process at any point, to single step through a task, and to observe in detail the performance of the control system. This is extremely important for program development and verification in a sophisticated, real-time, sensory-interactive system in which many processes are going on in parallel at many different hierarchical levels.

The hierarchical control structure just described is a generic concept which can be extended to apply to a wide variety of automated manufacturing systems. NBS plans to use this conceptual framework for the control system and data base architecture for the AMRF. *Figure 7* is a block diagram of the control system planned for the AMRF. The square boxes arranged in the hierarchical structure in the center of the figure represent the task decomposition modules at the various levels of control.

At the lowest level in this hierarchy are the individual robots, N/C machining centers, smart sensors, robot carts, conveyors, and automatic storage and retrieval systems, each of which may have its own internal hierarchical control system. The bottom row of boxes represents the control systems for these individual machines. The small subboxes labeled S and C correspond to the sensory and command interfaces to these control systems. The command input to the robot in *Figure 7* corresponds to the H3 Elemental Move Module input in *Figure 5*.

The bottom row of control modules in *Figure 7* is organized into work stations under the second row of work station control modules. A work station may consist of a machine tool, a robot, and a set of smart sensors. It may also consist of a set of robot carts, or an automatic storage and retrieval system with its associated robot. A machine work station control module accepts input commands of the form <MACHINE PART X>. A material handling work station may accept commands of the

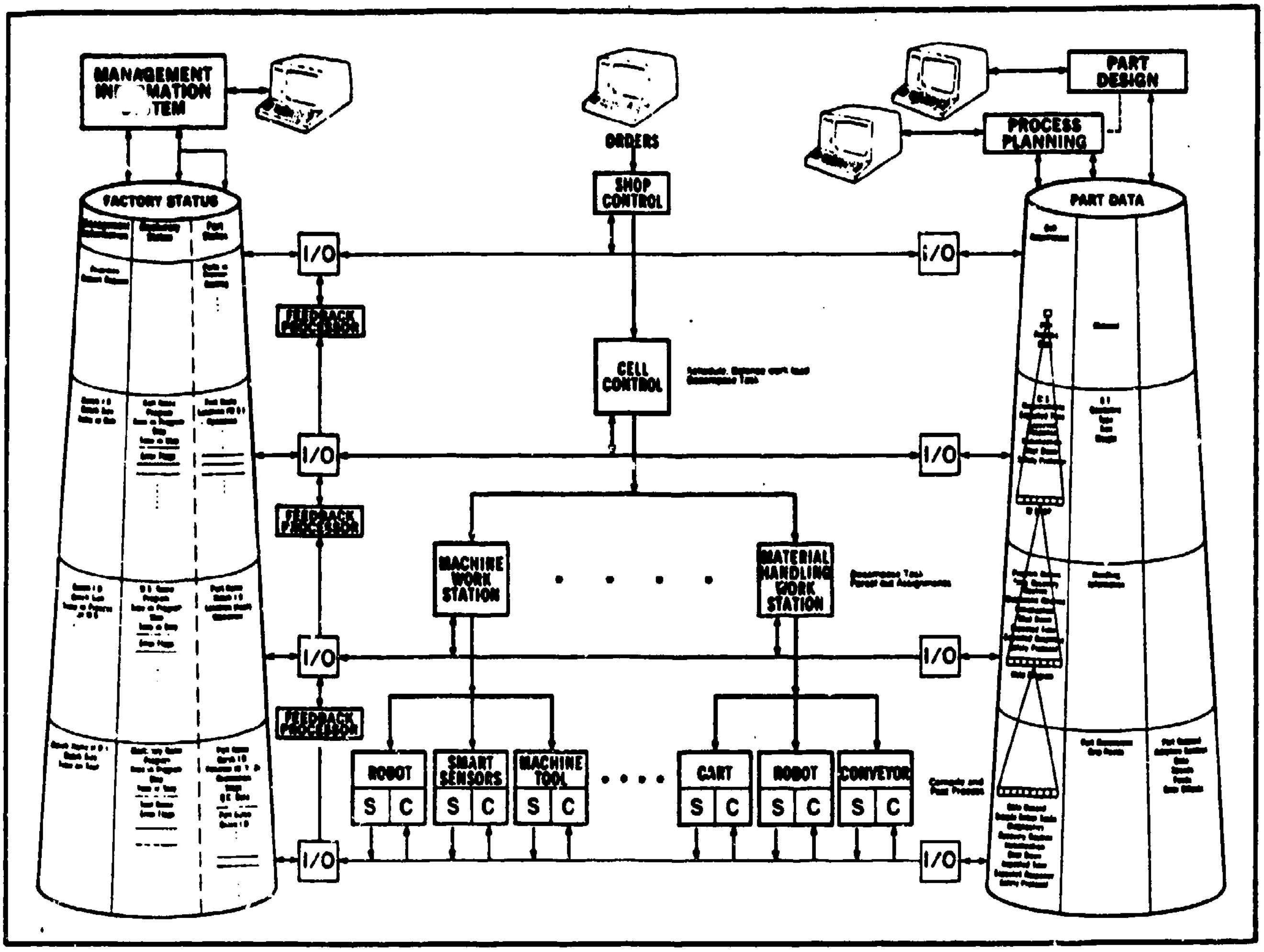

Figure 7
Schematic of Hierarchical Control as Applied to the Factory of the Future

form <MOVE TRAY Y TO WORK STATION Z>. The machine work station controller decomposes its commands into sequences of subcommands to the machine controllers of the form <FETCH PART X>, <INSERT X IN FIXTURE Y>, <EXECUTIVE CUTTING PROGRAM Z>, <CLEAR CHIPS>, etc. The material handling work station decomposes its commands into sequences of subcommands of the form <DISPATCH CART A TO PICKUP STATION B>, etc. In both cases, the decomposition is performed in the context of feedback information that is passed through the factory status data base shown on the left of *Figure 7*.

The work station controllers may contain programs written in the form of state-tables, or production rules. This formulation will allow the behavior of the work station to adapt to unexpected conditions such as broken tools or defective or missing parts.

Several work station control units are organized under and receive input commands from a cell control unit. The cell controller schedules jobs, routes parts and tools to the proper machines, and balances the workload among the work stations under its control. The cell controller makes sure that each machine has the proper tools at the proper time to perform the required work on each part.

Programs in the cell controller are also written in state-table form and can contain any number of rules for adapting to error conditions such as tool failures or changing priorities.

Several cells could be organized under a shop control unit. However, the AMRF initially at least,

will be considered as a single cell, and hence only one cell controller is planned. The possibility exists for either further expansion of the AMRF or emulation of other cells if the research task demands it.

There are two data bases planned for the AMRF. On the right of *Figure 7* is a Part Data Base which contains design data such as part dimensions, desired grip points for robot handling, group technology codes, and material and tooling requirements. A second section of the right-hand data base contains process plans for routing and scheduling and robot handling as well as cutter location data files needed for performing the various machining operations. These process plans are, in fact, the programs required at the various levels of the control hierarchy in order to perform the necessary manufacturing operations. Thus, the right-hand data base is, in part, a program library which contains the control programs needed by the control modules at the various levels of the control hierarchy. A third section of the right-hand data base contains data related to feeds and speeds which may be changed as a result of sensed conditions in the factory environment.

When an order is entered into the shop control module, the process plan to make that part is called in from the right-hand data base. The process plan is hierarchically structured so that at the top there is only the name of the process plan. This name is sent to the cell control. The cell control computer accesses the data base which calls in the sequence of steps (i.e., the program) that is the process plan at the cell level. Each command in this program is passed in sequence to the next level down, which is the work station. As each cell output command enters the work station, it is the name of a process plan for the work station. The work station then goes to the part data base as its level and calls up the sequence of instructions required to decompose that process plan for the robot or for the machine tool.

The data that reside in the part data base come from an interactive design graphics system and an interactive process planning system shown at the top right of *Figure 7*.

On the left of *Figure 7* is a second data base which contains dynamic Factory Status information. This Factory Status data base is also divided into three parts. On the far left is a management information and control data base. Entries or queries to and from this data base enable management to monitor and manage the whole factory by setting priorities or entering control parameters which alter the mode of operation of the control hierarchy.

The second section of the Factory Status data base contains the status of each machine tool and robot in the plant as well as the status of each computer in the control hierarchy: What program is each machine running? What step in the program? How long in that step? What part is being operated on?, etc.

The third section of the Factory Status base contains the status of each part in progress. In this data base, there exists a data file corresponding to every part that gives the part name, the tray that is transporting it, its position and orientation in that tray or in the work station, its state of completion, and a number of quality control parameters.

All these data bases are served by several Input/Output (I/O) controllers. The Factory Status data base also has a hierarchy of feedback processors that scan the various levels of the data base and extract the information needed by the control modules at the next higher level. As in the microcomputer robot control network, information is passed from one level to another, and from one computing module to another through the data base which serves as a common memory. This makes the system modular and defines the interface between modules to be the data base. Thus, specification of the data base specified the principal interfaces of the control system. This means that as long as a robot or machine tool controller can read from and write to the data base, it can be added to or deleted from a system with a minimum of impact on the other components of the system.

Because the status data base will be updated at each time increment, it will always contain a complete and current state description of the entire factory. This will make it possible to restart the system easily in the event of a computer system crash. It will also be useful as a debugging tool. Activities of the various modules and of the system variables themselves can be traced and recorded for debugging, analysis, or optimization.

The control architecture has been described in considerable detail since it is this feature that most clearly distinguishes the AMRF from "just another FMS". This system will provide the modularity

needed to carry out the NBS research program in interface standards and will eventually make FMS technology practical for many smaller shops.

Concluding Remarks

Although it will require a certain amount of research to construct the AMRF and to test the concepts on which it is based, the AMRF itself is not considered a research project. As various portions come on line, research projects, often with university or private sector cooperation, will be started. Many of these projects will deal with new and improved sensors to monitor machine performance. Others will deal with the problem of calibrating sensors so that the product dimensions (not the sensor responses) are traceable to National Standards. If more than one machine is involved in the manufacture of a part so that the refixturing effects the critical dimensions, this traceability becomes a complex problem. How both the mechanical operations and their supporting software are validated opens vast new areas for Measurement Assurance Program technology. Along with this metrology research will go research on the detailed nature of the data formats at each interface to determine how standards can be designed so as to neither compromise proprietary interests, nor inhibit innovations. The AMRF, like other Bureau facilities, will be made available to university and industrial groups for nonproprietary research in manufacturing engineering which lies further afield than the metrology and standards of NBS.

The AMRF is only one in a continuing series of facilities that permit NBS to fulfill its designated role as the nation's measurement and standards laboratory.

Acknowledgements

The Automated Manufacturing Research Facility* owes its existence to the foresighted management of the National Bureau of Standards and the Department of Commerce, and the support and encouragement of the machine tool community, especially those who have joined in the program as Research Associates. The support of the Department of Defense at various points in the program has been most helpful as has been the university community working with us both informally and under what is hoped to be an expanding grants program. The AMRF is truly a National effort.

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Author(s) Biography

Dr. John A. Simpson is presently Director of the Center for Manufacturing Engineering at the National Bureau of Standards (NBS), with background in the fields of dimensional metrology, electron optics, photo-optical instrument design, and mechanics. Prior to his appointment to this position, Dr. Simpson served as Chief of the Mechanics Division, Deputy Chief of the Optical Physics Division, and Chief of the Electron Physics Section, all at NBS, and was a Research Physicist at Lehigh University.

Dr. Simpson is a Fellow of the American Physical Society and has been active in its Division of Electron Physics. He has served on the National Academy of Sciences/National Research Council Panel for NATO Postdoctoral Fellowships. In 1975, he received the Department of Commerce Gold Medal award in recognition for his accomplishments in modernizing the metrology services of NBS. In 1980, he received the NBS Applied Research Award (jointly) for his part in the development and implementation of the automated, self-correcting three-axis coordinate measuring machine which enables manufacturers to characterize and correct errors in machine tools during manufacturing processes.

Dr. Robert J. Hocken is presently Chief of the Automated Production Technology Division at the National Bureau of Standards, with background in the areas of critical phenomena, machine tool metrology, three-dimensional metrology, laser optics, manufacturing technology, and polarimetry. His division at NBS develops and maintains competence in machine tool dynamics, precision engineering, robotics, and computer aided manufacturing, and is concerned with the incorporation of metrology into the precision metal working processes, including the standards necessary for integration of equipment up to the manufacturing cell level. Prior to appointment to this position, Dr. Hocken held a National Research Council Postdoctoral position at NBS, was Leader of the Dimensional Metrology Group, and Chief of the Dimensional Technology Section at NBS.

Dr. Hocken is a member of the American Physical Society, the American Society for Testing and Materials, and the International Institute for Production Engineering Research. He is a widely recognized expert in production metrology and recipient of the Taylor Medal of CIRP for contributions to metrology, the Department of Commerce Silver Medal for three-dimensional metrology, the IR-100 Award for the large-scale measuring machine, and the NBS Applied Research Award (jointly) for the development of the three-axis measuring machine which enables manufacturers to characterize and correct errors in machine tools during manufacturing processes.

Dr. James S. Albus is presently Acting Chief of the Industrial Systems Division and Manager of the Programmable Automation Section, Center for Manufacturing Engineering, National Bureau of Standards. He has received the Department of Commerce Silver Medal for his work in control theory and manipulator design and the Industrial Research IR-100 award for his work in brain modeling and computer design. He is the author of numerous articles in technical journals including a survey article on robot systems for *Scientific American* (February 1976) and an entry to *Encyclopedia Americana on "Robots"*. He has written articles on robotics for *OMNI* Magazine, *Metal Working News*, and *BYTE* Magazine. Dr. Albus has also been quoted in other national magazines, such as *TIME, Fortune, Reader's Digest, NEXT*, and *Discover*, and has appeared in a number of TV interviews.

Before coming to the Bureau of Standards, he designed electro-optical systems for more than 15 NASA spacecraft, seven of which are on permanent display in the Smithsonian Air and Space Museum. For a short time he served as program manager of the NASA Artificial Intelligence Program.

His latest book *Brains, Behavior and Robotics* was published by McGraw-Hill in November 1981. Dr. Albus has also written a book entitled *Peoples' Capitalism: The Economics of the Robot Revolution* in which he addressess some of the central social and economic issues raised by the advent of computer controlled robot industries.

APPENDIX H:

REVOLUTION IN CAR MAKING - PRECISION BODY FIT WITH BOLT-ON PLASTIC PANELS

Revolution in car making

—precision body fit with bolt-on plastic panels

A unique building method yields a rival for the fit and finish of imports

By JIM DUNNE
ILLUSTRATION BY JOE LAPINSKI

The giant machine crouches in the corner of the noisy assembly plant like some mammoth creature eyeing its quarry. A silvery car frame approaches. The machine lashes out with its metal tongue, noisily engorging its skeletal prey. It turns and tips and pushes the car into place, then clamps it hard. A cluster of tentacles descends from above and delicately chews through plastic and metal blocks on the frame—fashioning it in a way never before seen on an automobile assembly line.

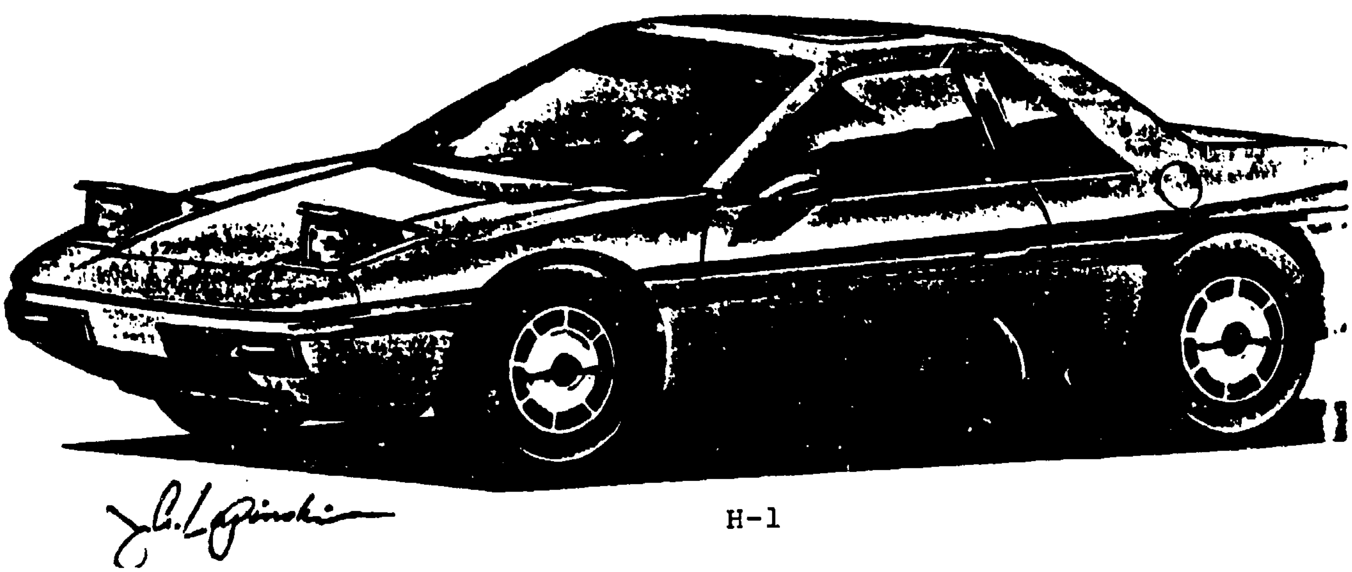
This September, when GM's Pontiac division unveils its new P-car two-seater, Fiero, this scene will be repeated some 30 times an hour. Fiero's construction will mark a major change in the way a car is put together—a revolutionary departure. Where cars were once made with a body and chassis and later with a unit body, Fiero will be made with a space-frame chassis and a separate covering of body panels. And while American manufacturers are sometimes chastised for the poor fit and finish of their cars, GM designers can boast a match for the fit and finish of Japanese and German cars—and go them one better, building body quality and flexibility of design into a car from its initial stages of production.

With the new technique, tolerances of 0.005 inch will be commonplace. What's more, the technology holds a promise of less-expensive body repairs for consumers. In many cases, body parts can be replaced with a few simple tools.

"Now we'll get body fits that can't be measured by the human eye," said Ernie Schaefer, manager of Pontiac's Plant 17 on the northern edge of Pontiac, Mich., where Fiero is to be built. "For instance, our critical door-to-front-fender seams will be held to tolerances that are closer than even skilled workers can gauge by sight."

What is this promising development? The key to the breakthrough is a huge machine tool called the Gilman Drill and Mill machine.

Ernie Schaefer recently escorted me on a tour of his plant, where I got a firsthand look at the machine and the line on which it plays a central role.

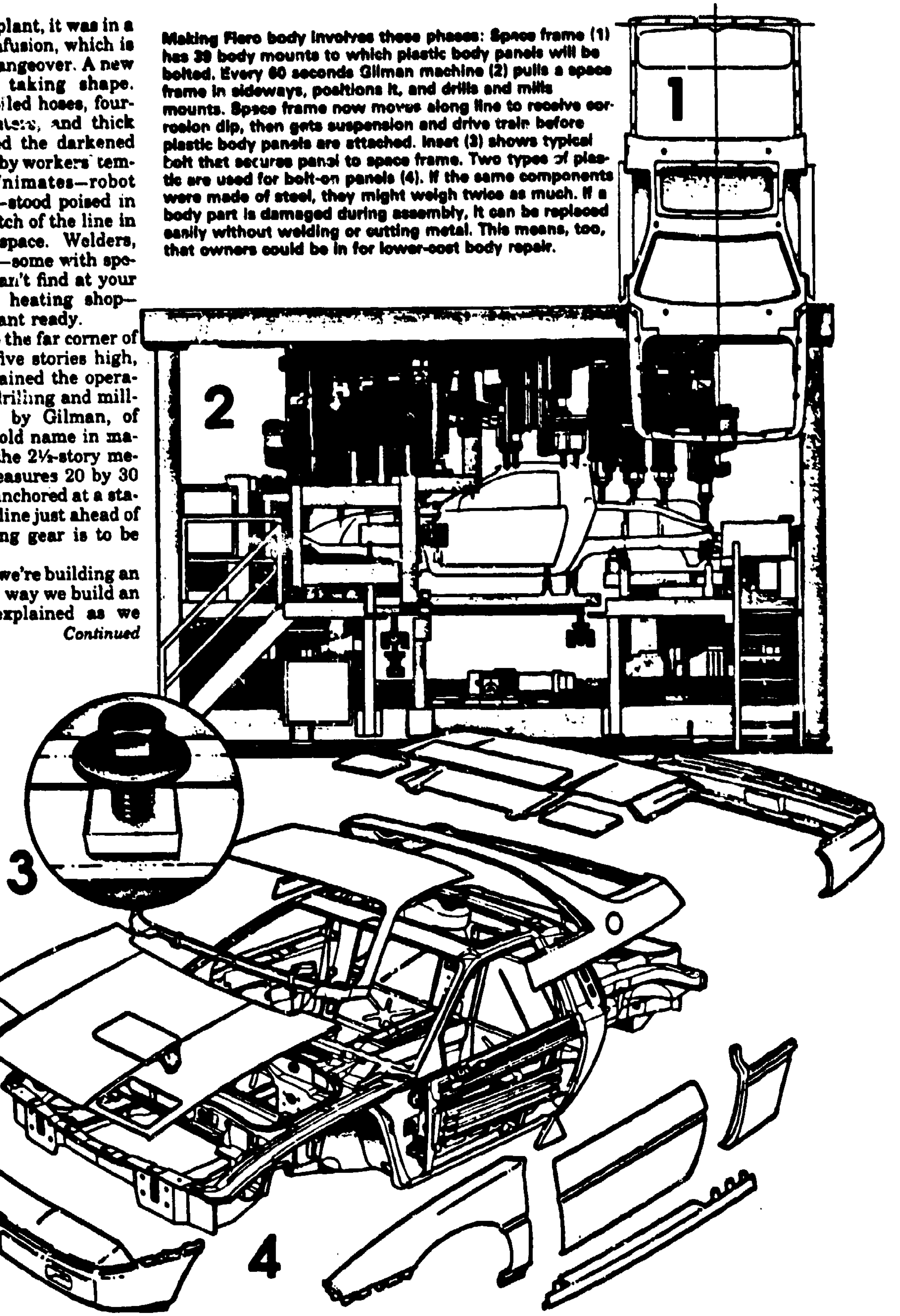


When I visited the plant, it was in a state of organized confusion, which is normal with plant changeover. A new assembly line was taking shape. Shiny new chains, coiled hoses, four-foot trenches, computers, and thick electrical cables filled the darkened interior, lighted only by workers' temporary fixtures. Unimates—robot welders, 22 of them—stood poised in flanks along one stretch of the line in the five-acre floor space. Welders, erectors, electricians—some with special skills that you can't find at your local plumbing and heating shop—hurried to get the plant ready.

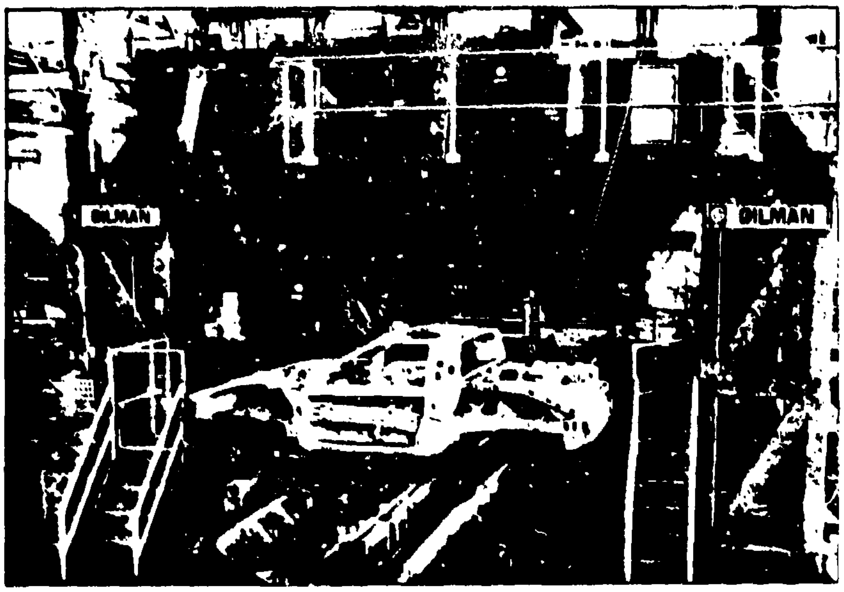
Our tour took us to the far corner of the plant, to a bay five stories high, where Schaefer explained the operation of a mammoth drilling and milling machine. Made by Gilman, of Janesville, Wis., an old name in machine-tool builders, the 2½-story mechanical complex measures 20 by 30 feet at the base. It's anchored at a station in the assembly line just ahead of where Fiero's running gear is to be installed.

"For the first time we're building an automobile the same way we build an engine," Schaefer explained as we

Continued



Making Fiero body involves these phases: Space frame (1) has 39 body mounts to which plastic body panels will be bolted. Every 60 seconds Gilman machine (2) pulls a space frame in sideways, positions it, and drills and mills mounts. Space frame now moves along line to receive corrosion dip, then gets suspension and drive train before plastic body panels are attached. Inset (3) shows typical bolt that secures panel to space frame. Two types of plastic are used for bolt-on panels (4). If the same components were made of steel, they might weigh twice as much. If a body part is damaged during assembly, it can be replaced easily without welding or cutting metal. This means, too, that owners could be in for lower-cost body repair.



P-car frame goes into Gilman machine in demonstration. If a frame is out of tolerance, the machine lowers it back to the conveyor and signals operator.

stood before the monster. "We machine parts of the frame to ensure a near-perfect fit with the body, just as we machine an engine block so that the head fits properly." If the Gilman Drill and Mill machine does its job right, there is virtually no way the body panels can be misaligned, whether installed at the factory or replaced later when a body shop—or Fiero owner—bolts on a new part.

Think of it this way: Parts of cars made the old way were put together with certain tolerances. But mismatches could add up—metal that was not formed precisely could result in parts that would be farther apart or closer together than planned. But this new system puts the frame together first, then locates the critical mounting points, resulting in better fits. In other words, it doesn't matter if out-of-tolerance figures add up; the ultimate fit is close to perfect, anyway.

"What we get is precise body building," said Schaefer. "And there are other benefits, too."

Some of the benefits stem from a change in the sequence of putting a car together. The space frame and chassis go together first; body panels are added as one of the last operations. Because the work of installing the engine, transaxle, suspension, and electrical parts is done on the space frame, assembly-line workers can't scratch the body. This also allows ample access to the inside through the gaps of the frame, easing some of the more intricate jobs.

The frame forms a cage for the body. It is built in a traditional way with huge welding fixtures and those robotic welders. The shape of the cage outlines the shape of the finished body, surrounding the passenger compartment and engine section (Fiero's engine is mid-mounted).

Drilling and milling

The Gilman pulls in the Fiero frame, positions it, and then drills and mills 39 body-mounting pads spaced along the top and sides—all in less than a minute. Eight clamps hold the frame. The door openings are sensed from three locations on each side of the frame, and an XYZ table (so-called after the three axes it aligns: fore-aft, up-down, side-side) positions the assembly. Then the drill heads bore the mounting pads, which are actually ¾-inch hard-plastic inserts. The drill bits vary in size from 5.2 to 10 millimeters (0.2 to 0.4 inches) and cut at two speeds: rapidly through the plastic, then more slowly through the frame so as not to distort it.

On the necks of the drills are tungsten-tipped milling inserts. They run at a relatively slow speed to machine the mounting pad to the design height.

"All the drills and mills are self-monitoring," reports Jim Werner, project engineer for Gilman, the man who directed construction of the Drill and Mill machine. "A load cell on each drill unit senses when the drill is cutting plastic or metal, or when a drill is chipped, broken, or missing. The cell controls the speed of the drills. If there is a problem with the bits, a control board signals a factory maintenance man to come over and fix it."

After passing through the Gilman cycle, the Fiero frame moves down the assembly line to take on its running gear and passenger-compartment dressing. Finally, the frame arrives near the end of the line, where body panels are attached. Workers use studs embedded in the plastic, or bolts that go through holes in the plastic, to hold the panels in place.

Two types of plastic are used for body parts: reinforced reaction injection molding (RRIM) for vertical surfaces such as fenders, and sheet-molded compound (SMC) for horizontal surfaces such as the roof. RRIM is reasonably stiff polyurethane, a "friendly" material that bends and snaps back after light impacts, cutting down on minor body damage. It's similar to the plastic used to cover modern bumpers. SMC is stiffer; it won't give as much when something is rested on its surface

Ron Rogers, the engineer in charge of the Fiero car project, says the plastic is unlike any other used in automobiles. "We put this plastic side by side with metal body panels and asked engineers to see if they could detect the difference. None could. With a new glass-flake process developed by GM, we avoid the wavy surface you see in fiber-strand-reinforced plastic. It's smoother by a factor of three."

Each of the panels is painted with a primer coat over its natural yellow hue, then comes a layer of color, and it's topped off with a clear-coat finish layer.

Using plastic makes it easy to fashion in one piece a complex body part that would require a number of welded pieces if made of steel. Look at the rear roof section of Fiero in the drawing. It trails down and curves around the upper part of the engine compartment. That couldn't be done easily in steel.

"We'd need maybe four welded parts to do the same job," says Rogers. "And that would mean more cost with less certain accuracy."

Plastic is a boon to stylists, too. By simply changing body panels on the space frame, a stylist can give the car a fresh appearance. Changeover time in the factory to a new body style would be negligible, and the same assembly machinery could be used without alteration.

The fabrication technique can work with steel body panels as well as it does with plastic. That means it could be used in volume-production sedans, where steel has a cost advantage over plastic.

With widespread interest brewing, even among Japanese and German car makers, chances are that many of us may have a space-frame car in our garage before the decade is over.